Instructions to Observers for Conducting Long-billed Curlew Surveys 2005

Background:

The Program for Regional and International Shorebird Monitoring (PRISM) is an attempt to deliver data-based population estimates for trend analysis of shorebirds. The temperate breeding group of PRISM is responsible for developing monitoring protocols for shorebird species which breed in the temperate zone of North America. Long-billed Curlew (LBCU) are designated as a Highly Imperiled species by the U.S. and Canadian Shorebird Conservation plans, as a Bird of Conservation Concern by the U.S. Fish & Wildlife Service (USFWS), a species of Special Concern by the Canadian Wildlife Service (CWS), an Audubon Watch List species, and a species of conservation concern in many states and provinces. Because of the need for an accurate range-wide population estimate for LBCU, this survey has been developed.

Protocol for conducting the Long-billed Curlew Range-wide Breeding Survey (LBCU RBS) is modified from Saunders 2001 and is designed to meet the statistical needs for estimating the breeding population of LBCU across their entire breeding range. Full background on the study is posted at http://mountain-prairie.fws.gov/species/birds/longbilled_curlew/. Routes were chosen according to a stratified random sampling scheme by the U.S. Geological Survey (USGS). More information on the selection of routes can be gotten from your primary regional contact or found at http://mountain-prairie.fws.gov/species/birds/longbilled_curlew/. Maps and route information, survey forms and protocol are provided to the surveyors from the USGS and USFWS. Training is provided for surveyors through the USFWS and USGS.

It is imperative that timing, routes, and data collection are followed as specified. If you are unable to conduct the survey according to the following designated protocol due to weather, road conditions or construction, or other unforeseen circumstances, and your concerns are not addressed here, please contact your regional contact immediately (Appendix A). Problems and deviations encountered during the survey should be noted on the data collection forms included with the packet.

Equipment and Training Needed:

Each team is made up of two observers. At least one member of the team must be familiar with the way routes are developed and have a strong understanding of the protocol. Both observers should have binoculars and each team will be required to provide reliable transportation, a watch with a second hand or a timer, GPS unit, thermometer, and any necessary reference books (Appendix B). A rangefinder, professional series compass, and a metric measuring device (e.g., measuring tape) are also helpful so that teams can check their distance estimations and directions. Maps, laminated "cheat sheets" (Appendix C), and data collection forms (Appendix D) will be provided to each team of observers. Observers must be able to identify LBCU by sight and sound and record behavior (Appendix E) and habitat characteristics (Appendix C and F) according to the prescribed categories and protocol. Appendix G lists some guides to assist in

plant identification and some illustrations of common species.

Data Collection:
Prior to the Start of the Survey

Familiarization with your route: In preparation to conduct the actual LBCU survey, it is suggested that, if possible, at least one of the observers drive the assigned route prior to the actual survey, to become familiar with the route and any possible complications. The routes are each 32-km (@ 20 mi) long with stops every 800 m (@ 1/2 mile) and follow improved roads when possible.

Two copies of each route map have been provided to each field crew. Route maps are printed using an ink jet printer and will run if they get wet. To avoid this, separate maps and keep one set in an accessible place where it can be used as a back up if needed. Use the other set during the actual survey. Place it in a protective plastic sheet and avoid contact with water.

Substitute routes have been assigned to make it easier to deal with changes in the field. In the event that inclement weather (snow, muddy roads, etc.) would create a hazard and/or jeopardize the completion of the survey during the specified time frame, please see the section below marked Weather. If a route needs to be moved because of dangerous conditions, because it would involve trespassing on private property, or because the route is impassable, as a last resort it can be altered. In this case, please contact your regional contact (Appendix A) and alter it according to the instructions found in Appendix H.

Familiarization with curlew survey forms: For each designated route there is a LBCU survey and a habitat data collection form (Appendix D). These forms will be filled out during the actual survey. As both observers will trade off data recording duties during the survey, both should become comfortable with the survey forms. The form will be used to designate survey conditions, number of curlews and their behavior, and general habitat information.

Equipment calibration: Equipment should be checked to make sure they are in proper working order and set to the right units. You are requested to use metric units when taking measurements. Within the U.S., set your GPS unit to read in UTM coordinates for your position format and map datum option NAD27 CONUS. Within Canada, set your GPS unit to UTM coordinates and NAD27 Canada. If your GPS unit does not automatically set your zones with the above information, you will need to do that as well. Compasses should be checked for proper declination at the start of each survey route.

You will need to be able to estimate the distance between yourself and the LBCU in distance bands of 0-400m, 400-800m, and > 800m. Rangefinders may have limited practicality in this process so you may choose to rely on your ability to accurately estimate distances. Check your distance estimation with a measuring tape or other measurement device regularly. If you do choose to use a rangefinder, be aware of their limitations and the conditions under which they will not give accurate readings. If you use a rangefinder make sure it is recalibrated at the start of each survey as well as during the survey if there is a chance they are no longer giving accurate readings (change in weather conditions, etc.).

Conducting the Actual Survey

Timing: Surveys are timed to coincide with the preincubation period of LBCU breeding phenology. This is the period of time when LBCU are thought to be most easily detected within their breeding habitat. There are four survey windows based on local conditions. Ideally, each route should be run within the specified period. If they cannot be run within this period, please contact your regional contact (Appendix A) immediately for further instruction.

Depending on the location of the routes, hypothetically, up to two neighboring routes can be run each day. Surveys should last about 6 hours. Start morning routes no earlier than 1/2 hour after local sunrise. You may also run a second route in the afternoon provided you can complete the survey without compromising the survey's integrity, observer safety, and end by 1/2 hour before local sunset. Routes should not be cut short to allow for additional routes to be run in a day. Consider how the survey may be affected by sun angle, observer fatigue and where you need to drive to for overnight accommodations and surveys the following day. A customized sunrise/sunset calendar for your location can be gotten from http://www.sunrisesunset.com/ or check your GPS unit for the information.

Weather: Please be aware of any predicted weather patterns which could affect the survey or make it hazardous for observation. Try not to conduct the surveys in high winds (>25 km/hr, >15 mi/hr, Beaufort Scale > 4), during moderate rainfall and/or snowstorm conditions. Local "normal" conditions may dictate the necessity to survey during higher wind periods in some parts of the range. Surveyors should use their best judgment on whether or not to discontinue a route if any of these conditions begin during the survey. Consider the type and severity of weather event and how much longer is needed to complete the survey route. Surveyors can "wait out" certain weather events, such as rainsqualls, if they will be brief in duration and they can complete the route within the day. Under no circumstances should surveyors put their safety at risk. Discontinue the survey if the weather is hampering ability to detect curlews or otherwise affecting their behavior. Be aware that driving on wet unimproved roads can be both dangerous as well as destructive (e.g. tearing up roads) and in some areas illegal.

If surveyors complete at least 12 stops of the route before the weather changes, and those stops fall within the randomly selected township, the data can still be used. For routes where less than 12 stops have been completed in the randomly selected township, and surveyors can complete the route during the same day, they may complete the route from the stop point later in the day if the weather conditions become more conducive. Surveyors can also return to the route the following day to complete a route. Start at the point the survey was discontinued the previous day. If possible begin at the time the survey was discontinued the day before as well. If at least 12 stops within the randomly selected township were completed, do not try to redo or finish the route at a later date but instead move on to the next route. Return forms from both the discontinued and the completed surveys.

Double observer and removal methodology: The double observer protocol (Nichols et al. 2000) and removal model (Farnsworth et al. 2002) are being followed during this study to test detection probabilities. Both papers can be found in Appendix I for your reference.

Observers must alternate between stops between being designated as the "primary" and the "secondary" observer. The primary observer's duties are to observe any and all curlews detected

and point them out to the secondary observer who will be recording the data at the stop point. It is important that the primary observer scan all four quadrants of the circle within the first 2 minutes of the 5 minute survey (otherwise the "depletion curve" may be aberrant and difficult to model properly). The secondary observer records all the information collected at the point from what the primary observer indicates and surveys the area independently to see if the primary observer has missed any curlews.

Birds which the secondary observer detects that are not detected by the primary observer are also recorded. One of the assumptions of the double-observer approach is that observations of the primary and secondary observers are independent. Therefore, the secondary observer should not point out or otherwise give any clues to the primary observer of any LBCU they may have missed prior to the completion of the 5 minute observation period. The secondary observer should mentally note the position of curlews undetected by the primary observer and take their measurements and record their observation only after the 5 minute observation period is completed. **It is imperative to data analysis to identify the primary vs. the secondary observer as having seen the curlew.**

Observers must alternate between being the primary and secondary observers. Having the same individual as the primary observer for all the odd numbered stop points and the other observer as the primary for all the even numbered stop points will cut down on confusion. **It is also imperative that any curlews not detected by the primary observer, but seen by the secondary observer, be noted as such on the survey data sheet** (see examples in Appendix D).

For each bird, the observers should ascertain the distance between the bird and observer (distance band of 0-400m, 400-800m, or >800m) and quadrant it is in. Note the identity of the observer and whether they were the primary or secondary observer at that stop. Record the time period (1-5 minute interval) within which the bird was first seen. Indicate how the LBCU was detected (sight, sound, or both).

Where possible and where the observer is certain, the sex of the LBCU should be noted. Males are generally smaller and have shorter bills than females. However, in most cases it will be unknown. Although most birds will be adults, if any downy young or juveniles are detected they must be noted. Behavior codes (Appendix E) and flock size should also be recorded in the comment section of the survey data sheet.

Driving the route: The routes do not have specified start or stop positions, and some of the routes are discontinuous. Surveyors may choose for themselves the best way to run a route. If bad weather is imminent, priority should be placed on portions of the route falling within the randomly selected township (this applies to all routes which spill over into adjacent townships). Routes were drawn to cover a distance of at least 32 km (20 mi), though for practical purposes they represent only an approximation of this distance. Surveyors may find the prescribed route is longer than 32 km. In this case, they should terminate the survey once they have surveyed 40 stop points. If surveyors find the route is too short (less than 32 km/20 mi, 40 stops), they should extend the route using the criteria specified in Appendix H. The starting point for a route will be designated as "Stop #1" and will be mile/km 0. Survey the designated route, as specified on the accompanying map, for 32 km/20 miles (40 stops). It is recommended to use the vehicle trip meter in conjunction with the map to keep track of the stops. Stop on the side of the road every

800 m (1/2 mile).

Be respectful of private property and do not attempt to cross locked gates or posted roads. In the event that surveying from the designated stop point could endanger you, skip the stop, make a note, and continue to the next stop. In the event that a stop point proves to have limited visibility because of visual obstructions (e.g., railroad beds, trees, etc.), it is still necessary to spend the time surveying it. In this case you will still be able to detect presence of LBCU by sound. You will estimate the percentage of the area where you cannot visually detect curlews on the habitat data sheet. Please note any deviations or problems on the data collection form. In the event that the entire route is unsafe or inaccessible, or other problems are encountered, choose from the alternate routes provided or contact your regional contact (Appendix A).

Field Forms: All data collected is to be entered on these forms. There are complete directions and examples to assist in completing the survey in Appendix D. Surveyors should familiarize themselves with the information needed at the start and end of the survey and the codes for LBCU, incidental species, and habitat data prior to the start of the survey. Please use the specified codes, including those for weather (sky codes, Beaufort wind scale). Fill in the required weather and observer information at the start of the survey. This information is also requested at the end of the survey.

Spend five (5) minutes listening and looking for curlews at each stop. Make all observations from the outside of the vehicle no more than 10 m from where the point is located. Do not walk into the field to collect data. Scan in all directions. Surveyors must spend the entire 5 minute period scanning and searching for LBCU, even if they "know" there are none there.

At each stop, regardless of whether a curlew is detected at that stop, complete at least one row on each of the field forms (habitat and survey data). If no curlews are detected at that stop fill in "NONE" under species. For each individual LBCU observed, complete a row on the field form. Record the time interval, observer, how detected, distance band between the LBCU and observer (0-400m, 400-800m, > 800m), and habitat type and height the curlew is in (5 m radius) for each sighting on the survey data sheet. Use the codes provided. **Please denote birds which enter the area during the 5 minute count.** Other information such as flock size, age, sex, and behavior will be used to answer assumptions regarding LBCU detection and survey timing. Records should reflect the distance, how the bird was behaving, and the habitat it was using based on when it was first sighted.

Although data analysis to arrive at population estimation will be limited to birds seen within 400 m of the observer, all birds seen should be recorded. Recording distances beyond 400 m will assist in describing the distribution of LBCU on the landscape. Count all birds seen or heard at the stop. In the case that a curlew follows observers (its movements are dependent upon theirs; e.g., a LBCU which is doing a distraction display) from stop to stop, only count it at the first stop it is detected. If a bird is flying between stops or is sited on more than one stop and is an independent sighting, it can be counted on all the stops at which it is observed (e.g., a bird which is flying from site to site for some other reason such as feeding). **It is imperative to distinguish between birds which are just passing over the area versus those which are using the area.** Please be sure to properly designate "fly overs" as FO in the comment section of the data sheet. Appendix E has additional information on LBCU behavioral codes and examples in Appendix D.

After the 5 minute survey period is completed, begin collecting the habitat data. Do not start collecting habitat data before the 5 minute survey period is completed. At each stop, record UTM units from the GPS unit, topography data, and percentage of habitat visible. Record habitat data, regardless of whether or not there are any curlews at that point, using the codes found on the laminated cheat sheet (Appendix C) and information provided in Appendix F. Examples are found in Appendix D.

Incidental species: If, during the survey, any of the incidental species are encountered at any of the points, please include them on the data forms. Each incidental species will also merit its own line. The incidental species of concern include temperate breeding shorebirds, grassland breeding owls, grouse, and mammalian predators (see list Appendix J). Include at least the stop number and species code. Behavioral, habitat and other data is optional for incidental species.

Return field forms: At the completion of each route, please make a copy of the data forms before sending in the original completed data sheets and route maps. This will ensure that there is a back-up copy of the data if it is needed. Please indicate any problems or deviations from the assigned route on the data sheet cover. Completed forms should be sent to your regional contact for consolidation (see Appendix A)

Literature Cited

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. Auk 119(2):414-425.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117(2):393-408.

Saunders, E. J. 2001. Population estimate and habitat associations of the long-billed curlew (Numenius americanus) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 25, Edmonton, AB

Appendix A
Regional Contact List

In the event of any problems with routes, need for alternate routes, assistance in altering routes, or questions about timing or anything else, please contact your regional contact.

Region 6 (CO, KS, MT, ND, NE, SD, UT, WY) and Canada (AB, BC, SK)

Stephanie Jones   <u>or</u>   Suzanne Fellows
U.S. Fish & Wildlife Service   U.S. Fish & Wildlife Service
PO Box 25486, DFC   PO Box 25486, DFC
Denver, CO   80225   Denver, CO   80225
303-236-4409   303-236-4417 (work)
Stephanie_Jones@fws.gov   303-909-1283 (cell)
                                        Suzanne_Fellows@fws.gov

Region 1 (CA, ID, NV, OR, WA)

Sue Thomas
U.S. Fish and Wildlife Service
911 NE 11th Ave
Portland, OR 97232
503-231-6164
sue_thomas@fws.gov

Region 2 (NM, OK, TX)

Bill Howe
U.S. Fish & Wildlife Service
PO Box 1306
Albuquerque, NM   87103
505-248-6875
Bill_Howe@fws.gov

USGS

Thomas R. Stanley   <u>or</u>   Susan Skagen
Fort Collins Science Center   Fort Collins Science Center
2150 Centre Ave, Bldg C   2150 Centre Ave, Bldg C
Fort Collins, CO   80526-8118   Fort Collins, CO   80526-8118
970-226-9360   970-226-9461
Tom_Stanley@fws.gov   Susan_Skagen@usgs.gov
home phone: 970-226-2915

Appendix B
Equipment List

Required Equipment
Binoculars (one per observer)
Reliable transportation
Watch with a second hand and/or Timer
GPS unit
Thermometer
Area maps or gazetteers
Code "cheat" sheets (Appendix C)
Data collection forms (Appendix D)

Optional Equipment
Reference books
Rangefinder
Metric measuring device (tape)
Cell phone
Plastic page protectors to keep maps from getting wet
Compass (must be able to set declination)

Provided by USGS/USFWS
Route maps

Appendix C
Survey and Habitat Codes

Long-billed Curlew Survey Codes

Sky Codes

0 Clear or few clouds
1 Partly cloudy
2 Cloudy (broken, overcast)
3 Rain
4 Fog or smoke
5 Drizzle
6 Snow
7 Showers (intermittent rain)

Topography

F	Flat
R	Rolling
P	Pocketed

Beaufort Wind Scale

0 Smoke rises vertically (<1 mph)
1 Wind direction shown by smoke drift (1-3 mph)
2 Wind felt on face, leaves rustle (4-7 mph)
3 Leaves, twigs in motion; light flag extended (8-12 mph)
4 Dust, loose paper blow; small branches in motion (13-18 mph)
5 Small trees sway, wavelets on water (19-24 mph)

Vegetation Height

Category	Height	In relation to LBCU
1	bare ground-4 cm (1 1/2 in)	can see foot
2	4-10 cm (4 in)	covers foot to "knee"
3	10-15 cm (6 in)	up to base of belly
4	15-45 cm (17 1/2)	up to back
5	45-65 cm (25 in)	up to eye level
6	≥ 65 cm (25 in)	above head

Species Codes

LBCU	Long-billed Curlew
NONE	Nothing seen

Incidental Species Codes

MOUP	Mountain Plover
WILL	Willet
UPSA	Upland Sandpiper
MAGO	Marbled Godwit
SEOW	Short-eared Owl
BUOW	Burrowing Owl
LPCH	Lesser Prairie-Chicken
GPCH	Greater Prairie-Chicken
STGR	Sharp-tailed Grouse
GSGR	Greater Sage-Grouse
CANLA	Coyote
VULVU	Red Fox
VULVE	Swift/Kit Fox
UROCI	Gray Fox
TAXTA	American Badger
MEPME	Striped Skunk
PROLO	Raccoon

LBCU Age & Sex Codes

AHY	after hatch year (adults)
HY	young of the year
DY	downy young
M	male
F	female
U	unknown sex

LBCU Flock Codes

1	Single
2	Pair
3	Flock: more than 1 bird and/or more than one obvious pair

LBCU Activity Codes

FE	Feeding: Actively pursuing food
R	Roosting: Actively roosting (eyes closed, one leg up, head under wing, etc.)
FO	Flying overhead: passing over area, not involved in territorial displays or other behaviors
T	Territorial displays: encounters between 2 or more LBCU, mate advertisement
N	Nesting: Includes copulating, scrape/nest building, egg laying, incubation, brooding young
D	Distraction displays: aerial or ground displays associated with nesting or young defense
M	Mobbing: specify observer, raptor, etc.

Habitat Codes

On Habitat Data Sheet: estimate the % (in increments of 25% or greater) in broad habitat classification categories by quarters (NE, NW, SE, SW) within the 400 m radius of the stop point. Record up to four (4) primary habitat codes in each quadrant and include all appropriate secondary codes and habitat conditions where they are easily determined. On the Survey Data Sheet: use the code which best describes the habitat being occupied by the LBCU, at first detection, within a 5-m radius of where the bird is located.

Primary Codes

GRAS	grasslands
RCWS	rural cultivated woodlands, scattered farm buildings, associated grounds, shelterbelts, orchard tree farms
CROP	cropland, planted growing crops, post-harvest stubble
BARE	barren ground, plowed not yet replanted, planted not yet growing
WEED	weedy fields; former grasslands, forb dominated fields
SHRB	shrubs clumped
STEP	steppe, widely dispersed shrubs with ≥50% grass
WOOD	woodlands
EMWL	wetlands/wet meadows
OWWL	open water wetlands, rivers, lakes, reservoirs, irrigation canals
STOK	stockpond, windmill
OTHR	urban residential and industrial miscellaneous
UNKN	cannot see due to topography or other visual obstructions

Secondary Codes

Grasslands
NTPA	native prairie
PAST	non-native, tame pasture/rangelands
CRPC	Conservation Reserve/ Permanent Cover Program
SHTG	shortgrass prairie: blue gramma-buffalo grass, includes cactus and small shrubs
MIXG	mixed grass prairie: wheatgrass-needlegrass
TALG	tallgrass prairie: wheatgrass-bluestem, needlegrass
TUND	alpine tundra and montane grasslands

Shrublands
SAGE	sagebrush *Artemisia-Agropyron*
SALT	saltbrush-shadescale-greasewood *Atriplex-Sacrobatus* alkaligrass
OAKS	oak shrub *Quercus gambelli*
MTSG	mountain shrublands mixed species *Cercocarpes*
WILC	highland willow carr *Salix*

Woodlands
CONF	conifer forest
RIPA	lowland riparian and hardwood bottomland *Populus-Salix-Acer*
ASPE	aspen *Populus tremuloides*
DECW	deciduous woodlands
MXFO	mixed deciduous-conifer woodland

Wetlands
EPHW	ephemeral/temporary ponds, wetlands, low wet prairie
SPLW	semipermanent lakes and ponds, shallow marshes
PLPW	permanent lakes and ponds, deep marsh
AKLW	alkali ponds & lakes, intermittent alkali
FENW	fen (alkaline) bog, wet meadow

Other
URCP	urban residential and parks
UIND	urban industrial, downtown, commercial districts
ROCK	rocks
OILP	mining pits, oil wells/pipes
HPLT	high power tension lines/poles
FLOT	feedlot
MISC	miscellaneous: specify

Tertiary Grassland Codes

Grassland foliage structure: don't include seedheads
SHRT	short grass, < 5" / < 12cm
MEDM	mid grass, 5-15" / 12-38cm
TALL	tall grass, >15" / > 38cm

Habitat Conditions

Management tool
GRAZ	grazed (cattle currently on, fresh pies)
BURN	burned (presence of ash or soot, black ground)
MCUT	mechanically cut: mowed, hayed
IR	irrigated grasslands, croplands, etc.
DY	dryland cropland, tame pastures

Invasive species
INVA	invasive species, particularly grasses, e.g. cheat grass (*Bromus tectorum*), Kentucky blue-grass (*Poa pratensis*), other bromes (*Bromus* spp.), etc. Indicate species and estimate %

Burrowing mammals
PDOG	prairie dog town
RGSQ	Richardson's ground squirrel
	AC active town (# mounds total)
	IA inactive town (# mounds total)

Appendix D
Data Collection Forms, Examples, and Instructions for Completing Them

Long-billed Curlew Range-wide Monitoring Survey Data Sheet

Survey Route State and Number:_____

Observer A:_____ (_____)

Date:_____

Observer B:_____ (_____)

Start Time:_____ Start GPS reading:_____

End Time:_____ End GPS reading:_____

Weather at Start:

Weather at End:

    Wind:_____ Sky:_____ Temp:_____C/F

    Wind:_____ Sky:_____ Temp:_____C/F

| Stop # | Min | Obs | Species | How Detected | Distance | | | Degree/ Quad | Habitat | | Comments (juveniles, courtship behavior, flyovers, flock size, sex) |
					0-400m	400-800m	>800m		Code	Height	

Route State/Number:_____ Date:_____ Supplemental Page No:_____

Observer A:_____ Observer B:_____

Stop #	Min	Obs	Species	How Detected	Distance			Degree/ Quad	Habitat		Comments (juveniles, courtship behavior, flyovers, flock size, sex)
					0-400m	400-800m	>800		Code	Height	

Route State/Number:_____ Date:_____ Supplemental Page No:____

Observer A:_____ Observer B:_____

Stop #	Min	Obs	Species	How Detected	Distance			Degree/ Quad	Habitat		Comments (juveniles, courtship behavior, flyovers, flock size, sex)
					0-400m	400-800m	>800		Code	Height	

Route State/Number:_____ Date:_____ Supplemental Page No:____
Observer A:_____ Observer B:_____

Stop #	Min	Obs	Species	How Detected	Distance			Degree/ Quad	Habitat		Comments (juveniles, courtship behavior, flyovers, flock size, sex)
					0-400m	400-800m	>800		Code	Height	

Example 1: Survey Data Form

Long-billed Curlew Range-wide Monitoring Survey Data Sheet

Survey Route State and Number: ____WY 51132   Savery____

Date: __24 April 2005__

Start Time: __0754__   Start GPS reading: __13 T 0272981-4623822__

Observer A: ____John L. Doe____   (JLD   )

Observer B: __Petunia M. Flower__   (PMF   )

End Time: __1325__   End GPS reading: 13 T 0264762-4626138

Weather at Start:

Wind: __1__   Sky: __0__   Temp: __52°F__ C/F

Weather at End:

Wind: __3__   Sky: __0__   Temp: __68°F__ C/F

Stop #	Min	Obs	Species	How Detected	Distance 0-400m	Distance 400-800m	Distance >800m	Degree/ Quad	Habitat Code	Habitat Height	Comments (juveniles, courtship behavior, flyovers, flock size, sex)
1			NONE								
2	3	PMF1	LBCU	V			X	NE	UNKN		flew in during survey; AHY, T, 1, U
3	1	JLD1	LBCU	B	X			NE	SHRB-SAGE	4	AHY, FE, 1, U
4			NONE								
5	1	JLD1	LBCU	A	X						same as below--never seen by 1° observer
	1	PMF2	LBCU	B	X			NE	GRAS-SHTG-SHRT	2	same bird as above, 2° saw and heard it; AHY, R, 1, U
6			NONE								
7	2	JLD1	MAGO	B		X		SW	CROP-DY	1	AHY, FE, 1, U
	4	JLD1	LBCU	V			X	SW			FO, 1
etc.											

Stop #	Min	Obs	Species	How Detected	Distance 0-400m	Distance 400-800m	Distance >800	Degree/ Quad	Habitat Code	Habitat Height	Comments (juveniles, courtship behavior, flyovers, flock size, sex)
34	4	PMF1	LBCU	V	X			NW	GRAS-PAST-SHRT-GRAZ	2	AHY, FE 2, M
	4	PMF1	LBCU	V	X			NW	GRAS-PAST-SHRT-GRAZ	2	AHY, FE, 2, F
35	2	JLD1	LBCU	V		X		SW	EMWL-EPHW	2	AHY, R, 1, M
36	3	PMF1	LBCU	B	X			SE	GRAS-PAST-SHRT-GRAZ	2	AHY, FE, 2, M
	3	PMF1	LBCU	B	X			SE	GRAS-PAST-SHRT-GRAZ	2	AHY, FE, 2, F
	3	PMF1	LBCU	B		X		SE	GRAS-PAST-SHRT-GRAZ	2	AHY, FE, 2, M
	3	PMF1	LBCU	B		X		SE	GRAS-PAST-SHRT-GRAZ	2	AHY, R, 2, F
37	4	JLD1	LBCU	V		X		SE	GRAS-PAST-SHRT-GRAZ	2	AHY, R, 1, U
	5	JLD1	LBCU	B		X		SW	GRAS-PAST-SHRT-GRAZ	3	AHY, R, 1, U
38	3	PMF1	LBCU	V	X			NW	CROP--DY	1	AHY, F, 1, U
	2	JLD2	LBCU	V		X		NW			AHY, FO, 1, U; never seen by 1°
	3	JLD2	LBCU	V			X	NW			AHY, FO, 1, U; never seen by 1°
39	5	PMF2	UPSA	A			X				heard only, not detected by 1°
40		NONE									

Survey route information is put on the sheet:

State and number of route as well as the nearest town for cross reference are recorded. Observer 1 will be John Doe and he will be the primary observer for the odd numbered stops. Petunia M. Flower will be the primary observer for the even numbered stops. ***Designation for the primary and secondary observers is imperative for proper data analysis. Denote the birds seen by the secondary observer only if the primary observer did not detect the bird. Make it clear on the data sheet that a bird was only detected by the secondary observer.*** The date, start time and starting GPS reading are recorded on the sheet. Units should be UTM coordinates with GPS unit set to NAD27 CONUS (U.S.) and NAD27 Canada (Canadian provinces). Please inform your regional coordinator of any deviations. Use zone-easting-northing format. The weather at the start is recorded using the Beaufort Wind Scale and Sky Codes from the cheat sheet (located in Appendix C) and taking a temperature reading. Indicate if C or F degrees are used.

Stop 1: no birds seen

Stop 2: at 2 minutes 54 seconds, a lone LBCU flies into the area and lands calling about 900 m away. You can't see it once it lands but hear it in the same spot throughout the rest of the survey. It is seen by both observers.

Stop 3: primary observer sees and hears a LBCU within thirty seconds of the 5 minute survey period. It is within 400m in the NE quadrant. It is alone and feeding in some sagebrush which reaches the back of the LBCU. Sex is undetermined. All Habitat Codes, Vegetation Height Codes, Species Codes, and LBCU Age & Sex Codes, Flock Codes, and Activity Codes are on the cheat sheet located in Appendix C.

Stop 4: no birds seen

Stop 5: both observers hear a LBCU 45 seconds from the start of the survey, within 400m. The primary observer (JLD) never sees it, however the secondary observer (PMF) does see it. After the 5 minute survey period she points it out. It was roosting alone in the NE quadrant in 3" shortgrass prairie. Sex is undetermined.

Stop 6: no birds seen

Stop 7: primary observer sees and hears a marbled godwit 1 minute and 16 seconds from the start of the survey feeding alone in a dryland cultivated field 600m out in the SW quadrant. At 3 minutes and 17 seconds into the survey a single LBCU flies overhead in the SW quadrant. It doesn't land. JLD is not comfortable sexing birds on the wing.

etc.

Stop 34: there is a pair of LBCU seen at 3 minutes and 22 seconds from the start of the survey, within 400m feeding in the NW quadrant in a short grass pasture. There is an obvious difference in length of bill and size. PMF is the primary observer and sees both of them.

Stop 35: JLD is the primary observer and at 1 minute and 2 seconds into the survey he sees a single LBCU roosting in the SW quadrant in a wetland 600 m away. The water depth goes half way up the bird's leg. Based on bill length it is determined to be a male.

Stop 36: PMF is the primary observer and sees and hears two pairs of LBCU at 2 minutes and 24 seconds. One pair is feeding about 150 m in the SE quadrant. The other pair is 750 m away but also in the SE quadrant. One bird is roosting and the other is feeding. All birds are in a short grass pasture which has recently been grazed (there are fresh cow pies all around). Birds are sexed based on obvious size and bill length differences. These birds are also seen by JLD.

Stop 37: JLD is the primary observer and sees a LBCU roosting 650 m into the SE quadrant. It is standing on one foot with its bill tucked out of sight in a short grass pasture which has cows present. It is first sighted at 3 minutes and 54 seconds. A second LBCU at the stop is heard and seen at 4 minutes and 56 seconds. It is about 600 m away and is in the SW quadrant. It does not seem to be interacting with the first LBCU and is lying down in the grazed short grass pasture.

Stop 38: the secondary observer at this stop is JLD. He sees a LBCU flyover head without stopping across the NW quadrant about 450 m out at 1 minute and 35 seconds. He also sees another LBCU flyover at 2 minutes and 15 seconds about 900 m out over the NW quadrant. At 2 minutes and 39 seconds both observers see a single LBCU feeding in a dryland crop field 350 m into the NW quadrant. Neither of the flyover birds were seen by the primary observer PMF.

Stop 39: the secondary observer hears an upland sandpiper at 4 minutes and 45 seconds. The location can't be pinpointed but it sounded like it was a great distance away. It was not heard by the primary observer.

Stop 40: no birds seen.

The end time and ending GPS reading are recorded on the sheet. The weather at the end is recorded using the Beaufort Wind Scale and Sky Codes from the cheat sheet (located in Appendix C) and taking a temperature reading. Indicate if C or F degrees are used. Make sure all supplemental pages are numbered consecutively beginning with 1. Put the total number of pages (X) at the top of the first page (Page No 1 of X).

The GPS reading at the start of the survey should be the same on both the Survey Data Form and stop #1 of the Habitat Data Form. The GPS reading at the end of the survey should be the same on both the Survey Data Form and stop #40 (or what ever the last number of stops was) of the Habitat Data Form.

Long-billed Curlew Range-wide Monitoring Habitat Data Sheet

Survey Route State and Number:_____   Observer A:_____ (_____)

Date:_____   Observer B:_____ (_____)

Stop #	GPS Reading (zone-easting-northing)	Topo % Hab Visible	Habitat Classification by Quadrant			
			NE	SE	SW	NW

Route State/Number:_____ Date:_____ Supplemental Page No:____

Observer A:_____ Observer B:_____

Stop #	GPS Reading (zone-easing-northing)	Topo % Hab Visible	Habitat Classification by Quadrant			
			NE	SE	SW	NW

Route State/Number:_____ Date:_____ Supplemental Page No:_____

Observer A:_____ Observer B:_____

Stop #	GPS Reading (zone-easting-northing)	Topo % Hab Visible	Habitat Classification by Quadrant			
			NE	SE	SW	NW

Route State/Number:_____Date:_____ Supplemental Page No:____

Observer A:_____ Observer B:_____

Stop #	GPS Reading (zone-easting-northing)	Topo % Hab Visible	Habitat Classification by Quadrant			
			NE	SE	SW	NW

Example 2: Habitat Data Form

HABITAT DATA
Long-billed Curlew Range-wide Monitoring Habitat Data Sheet

Survey Route Number/Name:____WY 51132____Savery____

Observer A:___John L. Doe_____ (_JLD_)

Date:___24 April 2005_____

Observer B:___Petunia M. Flower_____ (PMF)

Stop #	GPS Reading (zone-easting-northing)	Topo % Hab Visible	Habitat Classification by Quadrant			
			NE	SE	SW	NW
1	13 T 0272981-4623822	R-100%	100% GRAS-SHRT-GRAZ	50% CROP-winterwheat-DY	50% CROP-corn-IR 50% BARE	100% GRAS-SHRT
				50% BARE		
2	13 T 0272200-4623854	F-100%	100% GRAS-SHTG-SHRT-PDOG-IA#34	100% GRAS-SHTG-SHRT-PDOG-AC#12	100% GRAS-CRPC-TALL	75% RCWS 25% OWWL-sewage
3	13 T 0271456-4623965	F-100%	100% SHRB-SAGE	100% WOOD-CONF	100% OTHR-ROCK	100% WEED-GRAZ
4	13 T 0271032-4624011	R-80%	25% GRAS-NTPA-MEDM	75% GRAS-PAST-SHRT-GRAZ	100% OTHR-URCP-SHRT-MCUT-IR-	100%WOOD-DECW
			75% UNKN	25% WOOD-RIPA-GRAZ	cemetery	
5	13 T 0270654-4624821	F-100%	75% GRAS-SHTG-SHRT	65% CROP-DY 35% BARE-IR	100% GRAS-NTPA-SHRT-MCUT-HPLT-	100% CROP-MCUT
			25% EMWL-SPLW	OILPx2	windmills x 15	
6	13 T 0270001-4624901	F-100%	100% GRAS-TALG-MEDM-HPLT	95% OTHR-FLOT	95% RCWS	75% BARE-GRAZ 25% STOK
7	0269925-4625023	F-100%	100% GRAS-PAST-TALL	50% BARE-DY 25% WOOD-ASPE	75% CROP-DY 25% EMWL-EPHW	100%EMWL-AKLW-dry
				25% EMWL-SPLW		
8	0269125-4625035	R-100%	66% STEP 25% WOOD-OAKS	75% SHRB-SALT 25% SHRB-SAGE	100% BARE-BURN evidence of burned PJ	100%WEED-MEDM-INVA-cheatgrass 75%
	etc.					
37	0265996-462598	F-100%	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ
38	0265789-4626015	F-100%	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% CROP-DY
39	0265013-4626118	R-100%	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ
40	13 T 0264762-4626138	F-100%	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ	100% GRAS-PAST-SHRT-GRAZ

Survey route information is put on the sheet:

State and number of route (nearest town optional for cross reference). Observer A will be John Doe and he will be the primary observer for the odd numbered stops. Petunia M. Flower will be the primary observer for the even numbered stops and is designated Observer B. Record the date in day month year format.

GPS coordinates: please use UTM units as described under "equipment calibration" in the "Instructions to Observers for Conducting Long-billed Curlew Surveys 2005". Please use the format "zone easting-northing".

Stop 1: NE quadrant is a grazed area (you see fresh cow patties) in short grass but you can't tell which grass species are present or if it is a tame or native prairie; the SE and SW quadrants are both equally planted and freshly plowed fields, the SE planted in winter wheat and the SW is an irrigated corn field; NW quadrant has grass less than 5" tall, again, you can't tell the species and there is no evidence of recent grazing. The topography is rolling but you can see the entire survey area.

Stop 2: NE quadrant has buffalo grass and some small shrubs and you see 34 prairie dog burrows, none of which look as though they are being used (no dogs, no fresh diggings, grown over), the height of the grass is less than 5"; SE quadrant looks like the NE quadrant but with 12 burrows and prairie dogs running around on it; SW quadrant has a Conservation Reserve Program sign and tall grass; NW quadrant has a farmstead with buildings and shelterbelt which covers about 3/4 of the area and a sewage lagoon covering the rest. The topography is flat and you can see the entire survey area.

Stop 3: NE quadrant is covered with sagebrush; SE quadrant is covered in pinyon-juniper; SW quadrant is bare rock; NW quadrant looks like a crop field which has been allowed to go wild--you see lots of forbs and some grass, and there are cattle present. The topography is flat and you can see the entire survey area.

Stop 4: NE quadrant cannot all be seen because most of it is behind a hill, the 25% you can see is a native prairie about 8 inches high; SE quadrant is a pasture land with grass about 3" tall, an unfenced riparian area going through the center of it and horses within the quadrant; SW is a cemetery with mowed grass and an irrigation system; NW quadrant is a mix of deciduous trees. The topography is rolling and you estimate that about 20% of the survey area is not visible.

Stop 5: NE quadrant has a wetland within a grassland, you recognize wheatgrass, needlegrass, and several native shortgrass species; SE quadrant has a planted crop, recently plowed areas and 2 oil pumps; SW quadrant is a windfarm, essentially a mowed native prairie with several windmills on it; NW quadrant is a harvested hay field with the previous year's stubble left on it. The topography is flat and you can see the entire survey area.

Stop 6: NE quadrant is a big bluestem prairie, most of which are about 12 inches tall, there are also electric lines running across the quadrant; SE quadrant is dominated by a feedlot; SW quadrant has buildings associated with the feedlot; NW quadrant is a bare field with evidence of cattle and several stock ponds. The topography is flat and you can see the entire survey area.

Stop 7: NE quadrant is a grassy field and you can see ridges where it was obviously plowed at one time, the grass is now about two feet tall; SE quadrant has pockets of aspen trees growing around wetland areas, between the trees it has been plowed for crops; SW quadrant has wetland areas without trees and has a crop which has just sprouted; NW quadrant has a dry wetland with heavy salt deposits around it leading you to believe it is an alkali wetland when there is water. The topography is flat and you can see the entire survey area.

Stop 8: NE is a hilly area with an equal amount of grass and shrub equally dispersed and several pockets of shrub oak; SE quadrant is a mixture of saltbrush, greasewood and sagebrush; SW quadrant looks like it was once a pinyon juniper covered mountainside but it has recently been burned and there is nothing growing on it now; NW quadrant is a weedy field with lots of 7 inch high cheat grass. The topography is rolling but you can see the entire survey area and you can see the entire survey area.

Stop 37: all four quadrants are non-native rangeland that are short in stature and grazed. The topography is flat and you can see the entire survey area.

Stop 38: NE, SE, and SW are non-native rangelands, short in stature and grazed; NW quadrant is a dryland cultivated field. The topography is flat and you can see the entire survey area.

Stop 39: all four quadrants are non-native rangeland that are short in stature and grazed. The topography is rolling but you can see the entire survey area.

Stop 40: all four quadrants are non-native rangeland that are short in stature and grazed. The topography is flat and you can see the entire survey area.

At the end of the survey make sure all supplemental pages are numbered consecutively beginning with 1. Put the total number of pages (X) at the top of the first page (Page No. 1 of X). The GPS reading at the start of the survey should be the same on both the Survey Data Form and stop #1 of the Habitat Data Form. The GPS reading at the end of the survey should be the same on both the Survey Data Form and stop #40 (or what ever the last number of stops was) of the Habitat Data Form.

Appendix E
LBCU Behavior

The following behavior descriptions are adapted from descriptions reported in Dugger and Dugger (2002) and Saunders (2001). Please be aware that for purposes of this study, the behaviors described by the aforementioned authors, may have been reclassified.

FE **Feeding: Actively pursuing food**

LBCU eat a variety of species of invertebrates (primarily crustaceans, bivalves, arthropods, insects, and a variety of worms) and will also feed on small vertebrates (they have been observed to take bird nestlings and eggs and fish).

They will peck, burrow probe (probing in burrows until prey is detected then rapidly probing to capture it), probe in the substrate, pause-probe (involves standing motionless for 5-10 secs, holding bill partially submerged and slightly agape, when prey is detected bill slowly moved down until with a sudden lurch it captures the prey), hawk for insects, flip dung piles, look and chase, and walk to nests where a parent bird has flushed to depredate nestlings and eggs.

Forage singly, in pairs, and in groups of 3-14 individuals.

LBCU have been recorded feeding in firm mud, high-tidal areas, soft mud, sand, low-tidal areas, on grasslands, freshly plowed fields, and wet pastures.

R **Roosting: Actively roosting**

There are many positions for roosting, loafing, sleeping, and sunbathing, include preening, stretching, scratching, bathing and anting activities which will be considered roosting behavior for this study.

LBCU may have one or both eyes closed, one leg tucked up under its breast feathers, and/or its head under wing. Often the tail droops below the level of its primaries, neck may be retracted into its shoulders, and its feathers are fluffed.

May also be seen roosting by sitting on the ground with both legs tucked under its breast. Do not confuse this with nest incubation or brooding of young.

Preening: may involve feather ruffling, rubbing top of head over back and sides and scratching.

Feather shaking: general shaking of body-feathers.

Two-wing stretch: slowly and deliberately stretches head, neck, and wings to full extent over back into the air.

Stretches legs backward, extended and held as wing on same side is partially extended and stretched backward and downward next to leg.

LBCU may "wing-raise" to maintain distance among individual flock members during loafing. While this has been described as being a territorial display, if it is not done as a nesting territory defense or mate advertisement, and is done in the context of roosting/loafing, please count it as a roosting behavior.

FO **Flying overhead**

LBCU are strictly passing over an area, are not involved in territorial displays, agonistic encounters, or mobbing or fleeing observers or potential predators. Do not use this code if other behaviors occur during their passage. This is strictly for birds

which are, independent from the observer, other LBCU, and other species, moving across the airspace of the stop point.

T   **Territorial displays**

Agonistic encounters or displays between 2 or more LBCU and displays for the purpose of mate advertisement and defense of a territory against conspecifics. Also early nesting behavior such as copulating, scrape/nest building, and egg laying.

Several different behaviors have been described including "hovering", "crouch-run", "upright-run", "concealment", "supplanting", and "feather-raising". The following are some of the cues to look for: aerial displays used by aggressive male to locate an opponent hiding on the ground, concluding with landing on the ground near the opponent. Lowered head, bill forward, body feathers fluffed, legs crouched, wings slightly raised, often running at an opponent. Neck extended, head held high, body angled above horizontal, often running toward a conspecific. Aggressor approaches opponent, suddenly disappears from sight by dropping to the ground, flattens body including bill to the ground, while opponent searches for concealed aggressor who periodically springs up at opponent in a crouched run. Aggressor flies or runs to a position of another trying to get it to give up its position. Males competing for a female will raise their body feathers, fan their tail and then terminate the action by shaking their feathers.

"Wing-raising", if one bird raises its wings over its back while in an upright position, among individual flock members to maintain distance between themselves, this is not to be considered in this study as a territorial display if the birds are loafing (roosting). Remember, here territorial display refers to the active agonistic *encounters or displays between 2 or more LBCU and displays for the purpose of mate advertisement and defense of a territory against conspecifics.*

Post-pairing territory defense is primarily done by the male. Territorial defense after pairing may include aerial pursuits and vocalization.

The "soft kerr-kerr" flight occurs when the male ascends vertically and then glides slowly down toward the ground with his wings curved downwards and calls a series of soft "kerr kerr" notes. Counter calling between neighboring curlew territories will also be considered here as territorial behavior.

The long "curluoo" call, also described as a "curl---e-e-e-e-u-u-u" and "purt-bur-bur-bur-e-e", is most frequently heard during prenesting periods. It is always given on the ground, frequently after alighting near other LBCU and frequently reciprocated. If bill sparring and chasing sequences result, consider that it may be a territory maintenance call and count it as a territorial behavior. It has also been suggested to serve a pair-bond maintenance function.

"Bounding SKK Flight" or "Undulating Flight Display" are described as the male climbing silently and steeply into the air with rapid, fluttering wing-beats to a height of 10-15 m then sets wings in a downward curvature and head is elevated slightly above body plane, slightly extended neck, legs tucked into body and slowly gliding down into this position, often coming within 0.3 m of the ground before ascending again. Soft "kerr-kerr" or "hee-who" calls during descent.

Unpaired males ground call.

Ritualized courtship scraping is performed by both pairs and tossing where both sexes stand inside or near scrape and toss bits of vegetation, sticks, rocks or other nesting materials into the scrape.

Copulation and precopulatory behavior including "courtship run" (male runs at female with neck retracted and back angled above horizontal, wings may be slightly raised and fan primaries) and "shaking" (male stands behind female with wings raised out to the side, tail cocked upward, neck outstretched and angle of back horizontal, male begins paddling feet rapidly moving side to side behind female, male simultaneously shakes head and bill out front ruffling female's feathers, display becomes more frenzied and may progress to with wings raised into bent position above back, where they are fluttered). Female may assume a more horizontal body position and male then mounts and copulates.

N **Nesting**

Lump all behaviors which indicate LBCU are no longer in the preincubation stage, incubation, and brooding young.

If at any time during a survey, young of the year LBCU are observed please indicate this on the survey form. This is imperative as it will indicate that our surveys are not during the preincubation stage and must be altered to an earlier time period.

The "curluoo" call may be given as an anxiety note after being flushed from the ground or when a potential predator threatens a nest.

D **Distraction displays**

Aerial or ground displays associated with nesting or young defense.

The "arc display call" consists of a long, harsh note, "guaaah", and a shorter "kieee" note ending with an undulating quality. Usually given in conjunction with defense of young or a late incubation nest against predators.

The "ki-keck" call, a trill with syllables most often grouped in twos or threes is almost always given in flight as a defense against a predator. This call is also given during mobbing.

"Wheet" call given during periods of anxiety when researchers approached pair too closely, within 50m of nest, vicinity of chicks or when flushed from ground.

M **Mobbing**

Mobbing behavior is characterized by one or more LBCU dive bombing or attacking usually avian predators during flight. If not associated with chick or nest defense specify as mobbing. Indicate the subject of mobbing (gulls, raptors, etc.).

The "ki-keck" call, a trill with syllables most often grouped in twos or threes is almost always given in flight during mobbing. This call is also given during distraction displays and in response to chicks.

Dugger, B. D. and K. M. Dugger. 2002. Long-billed curlew (*Numenius americanus*). *In* The Birds of North America, No. 628 (A. Poole and F. Gill, eds.) The Birds of North America, Inc., Philadelphia, PA.

Saunders, Elizabeth J. 2001. Population estimate and habitat associations of the long-billed curlew (*Numenius americanus*) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division, Alberta Species at Risk Report No. 25. Edmonton, AB.

Appendix F
Habitat Codes Explained

Refer to the codes on the habitat cheat sheet and plant illustrations in Appendix C and the LBCU survey and habitat forms and examples (Appendix D).

Observers will need to be able to identify the broad habitat classifications below. They will be used on the survey data sheet to estimate the immediate habitat the LBCU is using (5 m radius around the LBCU) and on the habitat data sheet to estimate the habitat found all four quadrants around the stop point (400 m radius around the stop point).

Habitat data should be taken after the 5 minute survey period has been completed. Make all observations from the stop point; do not walk into the field. The collection of the data is not intensive and should not take more than 2 minutes/stop. Look at each quadrant (NE, SE, SW, and NW) separately. For the landscape characteristics which contain $\geq 25\%$ of any of the classifications, include up to four primary codes. Designate the percentage (25-100%) of each classification. Total percentages in each quadrant should not equal more than 100%. However, the total may be less than 100% if there are primary habitat types which do not comprise at least 25% of a quadrant total.

Primary Codes: These can be completed even if you do not know anything about individual plant species. There are 13 primary codes:

Grasslands: Use the primary code **GRAS** for any grasslands. Secondary and tertiary codes as well as habitat condition codes will be used to further describe the type of grassland and are extremely important to include.

Rural Developments: Use the code **RCWS** to indicate a farmstead, scattered farm buildings or buildings associated with farming and or ranching operations, orchard/tree farms (regardless of species), shelterbelts, etc.

Cultivated: **CROP** indicates planted growing crops and post-harvest stubble. For cropland which has been plowed but not planted or planted but nothing is above ground, classify it as **BARE**. Please use habitat condition codes where appropriate.

Weedy Fields: In many areas former croplands and grasslands which have been plowed have become "weedy". Use the code **WEED** to indicate a field which is a forb-dominated grassland or cropland. Please use tertiary codes and habitat condition codes where appropriate.

Shrublands: Use one of two codes for the primary classification of the basic structures of shrublands: if shrubs are clumped and there is less than 49% grass within the area use **SHRB**. For an area in which grass makes up at least 50% of the cover and the shrubs are widely dispersed classify it as steppe (**STEP**). Please use secondary codes and habitat condition codes where appropriate.

Woodlands: Any noncultivated area with naturally occurring trees is classified as woodland

(**WOOD**). Use the codes under Rural Developments, Cultivated, or Other to indicate treed areas that are either associated with rural or urban development. Please use secondary codes and habitat condition codes where appropriate.

Water: There are three primary codes to use for water habitats found in the quadrants. Wet meadows, ephemeral, temporary, semipermanent, alkali wetlands, bogs, and marshes are all shallow water areas and should be coded **EMWL**. Reservoirs, lakes, rivers and large, deep open water wetlands and irrigation canals should be classified as open water areas, **OWWL**. In the case of stock ponds and tanks, sewage treatment ponds, and windmills indicate their presence as **STOK**. Please use secondary codes and habitat condition codes where appropriate.

Other: Urban residential and industrial areas as well as miscellaneous areas such as rock piles, cemeteries, etc. can be classified as **OTHR**.

Unknown: In the event that topography or other visual obstructions prevent classification of habitat, use **UNKN**.

Secondary Codes: Where more details can be quickly gathered please use the following classifications. These can be used to augment the primary codes where appropriate. There are illustrations of several of the key species in Appendix C. In many cases the identification of these species may be difficult especially during early season surveys where warm season grass seedheads have not yet appeared.

Grasslands: Native prairie (**NTPA**) consists of native grassland species including forbs and shrub species. This is a broad category but covers all nonbroken grasslands with native species. Planted pasture and rangelands (**PAST**) consist of many non-native species commonly crested wheatgrass (*Agropyron cristatum*). Conservation Reserve Program (U.S.) and Permanent Cover Program (Canada) grasslands (**CRPC**) can be either planted in native or non-native species. They may be indicated by a sign stating they are part of the CR/PC program. Shortgrass prairies (**SHTG**) consist of grass species such as grama (*Bouteloua*), needle (*Stipa*), wheatgrass (*Agropyron*), fescue (*Festuca*), and buffalo (*Buchloe*) and are often interspersed with cactus (*Opuntia spp.*), yucca (*Yucca*), forbs and small shrubs. Tallgrass prairies (**TALG**) consist of species of grasses such as bluestem (*Andropogon*), switch (*Panicum*), Indian (*Sorghastrum*), needle (*Stipa*), and wheatgrass (*Agropyron*), many forbs (especially Asteraceae and Fabaceae) and even trees. Mixed-grass prairies (**MIXG**) show a combination of both tall- and shortgrass prairie species. Alpine tundra and montane grasslands (**TUND**) are found in high elevation areas generally over 7000' (2100 m). Please include tertiary codes and habitat conditions where appropriate.

Shrublands:
Shrublands can be dominated by sagebrush (**SAGE**) *Artemisia spp.* and wheatgrasses *Agropyron spp.* Communities of saltbrush (*Atriplex spp.*) and greasewood (*Sarcobatus vermiculatus*) should be designated **SALT**. Designate oak (*Quercus gambelli*) shrublands as **OAKS**. Mountain shrubland communities dominated by mountain mahogany species (*Cercocarpus spp.*) are designated **MTSG**. Highland willow carr areas are dominated by willow (*Salix spp.*) and designated **WILC**. Please include habitat condition codes where appropriate.

Woodlands:
Conifer (**CONF**) forests are natural wooded areas composed of *Pinus*, *Psuedotsuga*, *Abies*, *Picea*, *Larix*, *Juniperus*, and/or *Tsuga*. Lowland riparian and hardwood bottomlands (**RIPA**) are streamside woodlands dominated by *Populus*, *Salix* and *Acer* species. **ASPE** consist of aspen (*Populus tremoides*) stands. Deciduous woodlands (**DECW**) are composed of other deciduous forests not classified above. Use the code **MXFO** for mixed woodlands of both deciduous and coniferous species. Please include habitat condition codes where appropriate.

Wetlands:
Where it is possible, please distinguish between ephemeral/temporary ponds and low wet prairies (**EPHW**) and semipermanent lakes and ponds, and shallow marshes (**SPLW**). Differences in vegetation will be your biggest key. Alkali ponds and lakes and intermittent alkali areas, as determined by salt deposits, should be designated **AKLW**, whether or not they are dry or wet. Permanent lakes and ponds as well as deep marshes should be coded **PLPW**. Fen areas can be designated **FENW**. Reservoirs, rivers, lakes and other open water areas are designated by **OWWL** as a primary code and do not require a secondary code.

Other:
Urban residential, park areas and urban cemeteries (**URCP**) and urban industrial, down town and commercial districts (**UIND**) could be encountered along the survey routes. **ROCK** designates bare rock, rock piles, rock quarries, and rock cliffs. **FLOT** designates feed lots. **OILP** can be used to designate areas with oil development and include oil pumps, pipelines, buildings and machinery associated with the extraction, storage and shipment of petroleum products. **HPLT** designates high tension power lines and poles, communication towers, and other structures associated with the electric or communication services. A miscellaneous (**MISC**) code is also provided for coding of any other structures which do not fit into any of the other classifications.

Tertiary Codes: These codes apply to grassland foliage structure. Look only at the height of grass foliage, as it is now. Indicate if the grass is **SHRT** (short < 5"), **MEDM** (medium 5-15") or **TALL** (tall > 15") in height. In this case do not include seedheads in your estimation. You do not need to know the species of grasses--this is just a measurement of height.

Habitat Conditions:
Management tools: Grasslands, croplands, and shrublands may be treated in several ways. Indicate if fields are irrigated (**IR**-center pivot or other mechanical watering device is present, evidence of water on field that is clearly not from natural precipitation) or dryland (**DY**). Indicate if irrigated based on observed irrigation systems, whether or not currently irrigating. If there are cattle in the quadrant or there is evidence of recent cattle grazing as indicated by fresh cow pies or other cues, please indicate **GRAZ** after the primary code. If the quadrant has recently been burned as indicated by black ground or the presence of ash or soot indicate **BURN**. If fields have been hayed or mowed or otherwise mechanically cut indicate with **MCUT**.

Invasive species: If you find invasive species indicate **INVA** and include the species and estimate the % in the quadrant. We will define an "invasive species" as one that is a) non-native (alien) to the ecosystem under consideration and b) causes or is likely to cause economic or environmental harm or harm to human health (www.invasivespecies.gov). Some of the more

common species may include cheat grass/downy brome (*Bromus tectorum*), Kentucky blue-grass (*Poa pratensis*), thistles, knapweeds, leafy spurge, salt cedar, Russian olive, pepperweeds, mustards, and whitetops. There are several illustrations of different species in Appendix C.

Burrowing mammals: If the quadrant includes a prairie dog, Richardson's ground squirrels, or other burrowing mammal town please indicate **PDOG** or **RGSQ** (note if other species) and indicate if the town is active (**AC**) or inactive (**IA**) and a rough number of mounds seen within the quadrant. A town is considered active if burrowing mammals are present or if there are fresh signs of activity (fresh diggings, fresh droppings, vegetation is clipped, etc.). A town is considered inactive if it is overgrown or there is no sign of any of the burrows being used. You do not have to distinguish between active and inactive burrows, this is just a measurement of the activity of the town as a whole.

Appendix G
Plant Field Guides and Illustrations

For the purposes of the rangewide LBCU survey, plant identification skills are not necessary. However, it is hoped that you will become familiar with some of the common species mentioned on the code sheet. If you are interested in expanding your knowledge, these are a few references. Illustrations included are a consolidation from the sources below and are provided to assist you in identifying the more common species mentioned from the habitat code sheet.

Agricultural Research Service, USDA. 1971. Common Weeds of the United States. Dover
    Publications, Inc., New York, NY, 463 pgs.
    ISBN: 0-486-20504-5
    Illustrations, range maps, and descriptions of common weed species across the US.

Barkley, T. M. 1983. Field Guide to the Common Weeds of Kansas. Univ of KS Press,
    Manhattan, KS, 164 pgs.
    ISBN: 0-7006-0224-0
    Line drawings for some of the more common weeds found in Kansas.

Blaisdell, James P. and Ralph C. Holmgren. 1984. Managing Intermountain Rangelands--Salt-
    Desert Shrub Ranges. USDA USFS Intermountain Forest and Range Experiment Station,
    Ogden, UT, 52 pgs.
    Photographs of habitats and shrub species. Not an identification guide.

Brockman, C. Frank. 1979. Trees of North America. Western Publishing Comp., Inc., Racine,
    WI, 280 pgs.
    ISBN: 0-307-13658-2
    Golden Field Guide to the major native and introduced tree species found north of
    Mexico. Color illustrations, range maps, and descriptions of several species found
    throughout the US and Canada.

Cooperative Extension Service. 1983. Range Grasses of Kansas. Kansas State Univ., Manhattan,
    KS, 23 pgs.
    Contains line drawings from several different sources of both native and introduced grass
    species commonly found in grassland areas.

Featherly, H. I. 1946. Manual of the Grasses of Oklahoma. Bulletin of the OK Ag. and
    Mechanical College, 43(21): 137 pgs.
    Key to grass species and some line drawings of seed heads.

Fort Hays State University. 1995. Pasture and Range Plants. Ft Hays State Univ., Ft Hays, KS,
    176 pgs.
    Colored drawings of common range and pasture plants found in KS.

Great Plains Flora Association. 1986. Flora of the Great Plains. Univ. Press of KS, Manhattan, KS, 1402 pgs.
ISBN: 0-7006-0295-X
Key and descriptions of plants found in the Great Plains. No illustrations.

Haukos, David A. and Loren M. Smith. 1997. Common Flora of the Playa Lakes. TX Tech Univ. Press, Lubbock, TX, 196 pgs.
ISBN: 0-89672-388-7
Primarily a wetland species identification guide however, there are photographs of grasslands and other playa lake species.

Hitchcock, A. S. 1971. Manual of the Grasses of the United States, volumes I and II. Dover Publ., Inc., New York, NY, 1051 pgs.
ISBN: 0-486-22717-0 and 0-486-22718-9
Pictures and descriptions of the grasses found across the US.

Larson, Gary E. 1993. Aquatic and Wetland Vascular Plants of the Northern Great Plains. Gen. Tech. Rep. RM-238, Ft Collins, CO:USDA, FS, Rocky Mountain Forest and Range Experiment Station. 681 pgs.
Primarily a wetland species identification guide.

Stubbendieck, J., Stephan L. Hatch, and Kathie J. Hirsch. 1989. North American Range Plants, 3rd ed. Univ. of Nebraska Press, Lincoln, NE, 465 pgs.
ISBN: 0-8032-9162-0
Drawings of range plants (grasses and forbs) found rangewide.

Taylor, Ronald J. 1992. Sagebrush Country: A Wildflower Sanctuary. Mountain Press Publ. Comp., Missoula, MT, 211 pgs.
ISBN: 0-87842-280-3
Gives excellent examples of the different types of habitats and photos of plants and grasses found in Great Basin habitats.

Van Bruggen, Theodore. 1983. Wildflowers: Grasses and Other Plants of the Northern Plains and Black Hills, 3rd ed. Badlands Natural History Association, Rapid City, SD, 97 pgs.
ISBN 0-912410-05-1
Grasses and other plants common to the Black Hills region of SD and WY. Photographs and descriptions arranged by flower color.

Whitson, Tom D., Larry C. Burrill, Steven A. Dewey, David W. Cudney, B.E. Nelson, Richard D. Lee, and Robert Parker. 1999. Weeds of the West. Pioneer of Jackson Hole, Jackson, WY, 630 pgs.
ISBN: 0-941570-13-4
Photographs and descriptions of weeds found in the western US and Canada.

Wingate, Janet L. 1995. A Simplified Guide to Common Colorado Grasses, 2nd ed. Wingate
    Consulting, Denver, CO, 31 pgs.
    ISBN 0-9647543-2-0
    Illustrated and simplified key to 100 of CO's 300 grass species based primarily on
    inflorescence. Drawings of grasses with comparison to human height to assist in
    identification.

WILLOWS
Salix
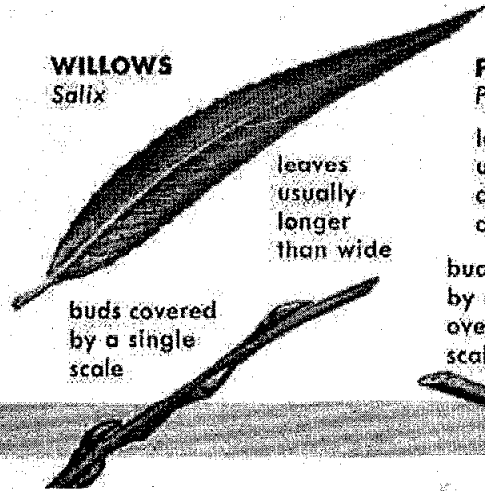
leaves
usually
longer
than wide

buds covered
by a single
scale

POPLARS
Populus
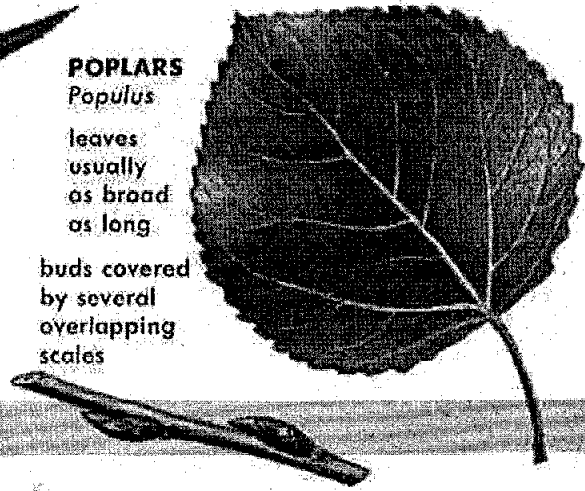
leaves
usually
as broad
as long

buds covered
by several
overlapping
scales

Populus spp. cottonwoods

leaves opposite;
usually palmately
lobed and veined.
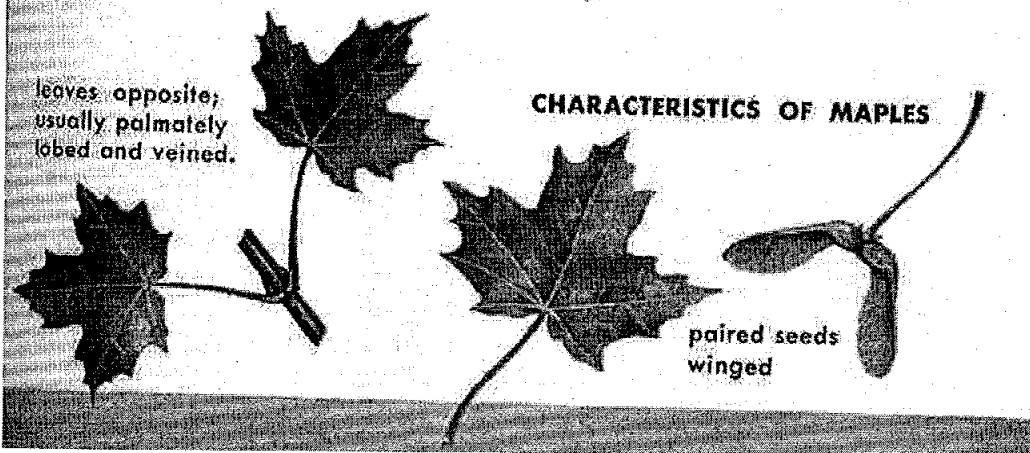
CHARACTERISTICS OF MAPLES

paired seeds
winged

Acer negundo

BOXELDER

Populus tremuloides:
Quaking aspen
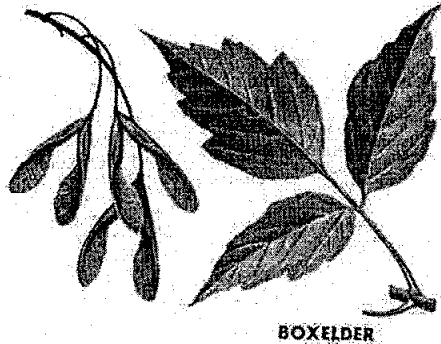
Cercocarpes spp.
Mountain Mahogany
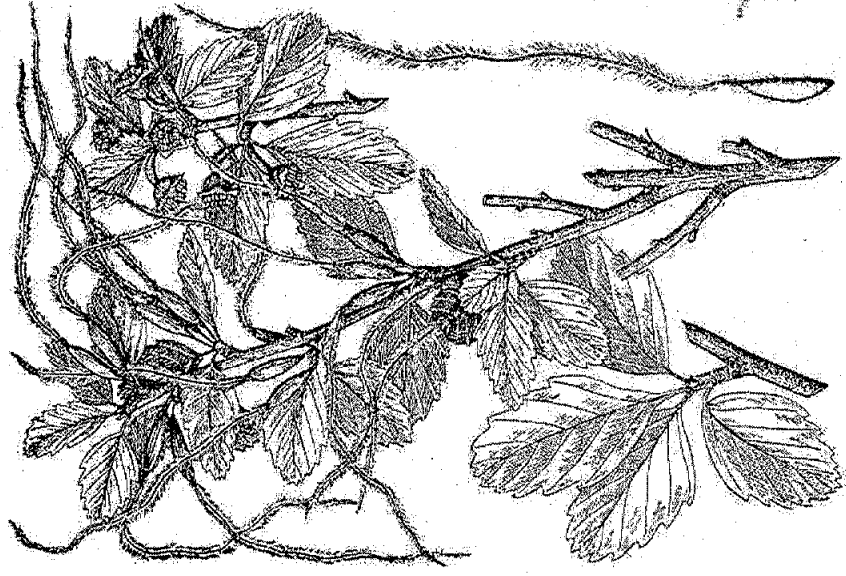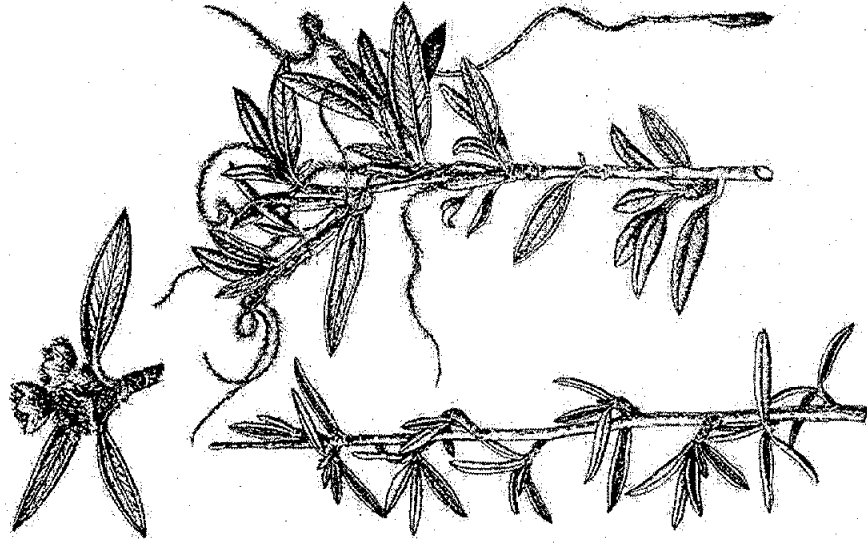
Quercus gambelli
Gambel Oak
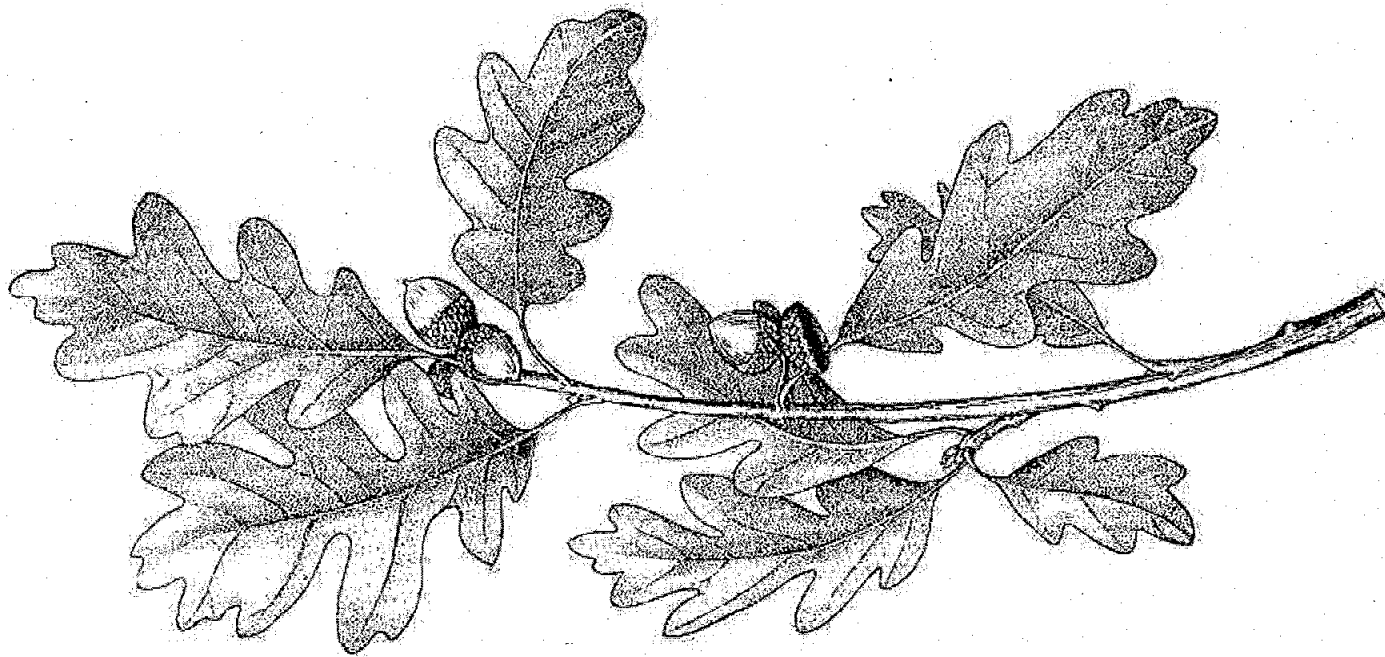
Artemisia – Agropyron
Sagebrush - Wheatgrass

Agropyron trachycaulum
Slender wheatgrass

Artemisia cana
Silver sagebrush

Atriplex – Sarcobatus
Saltbrush - Greasewood
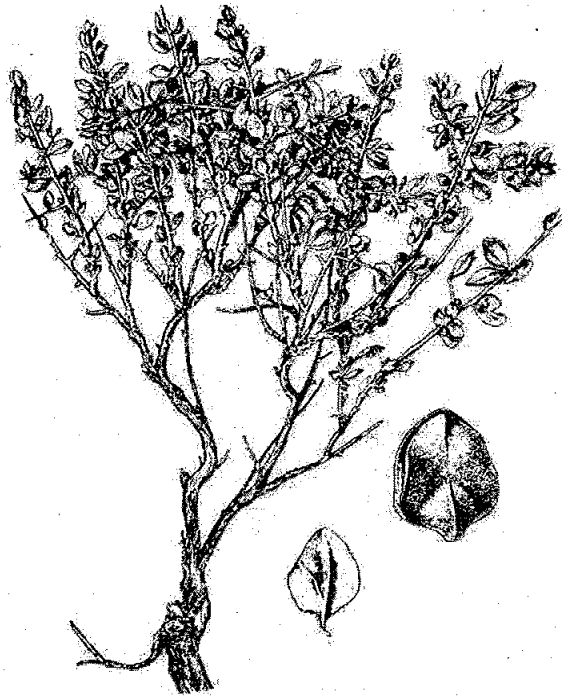
Atriplex confertifolia
Shadscale saltbrush
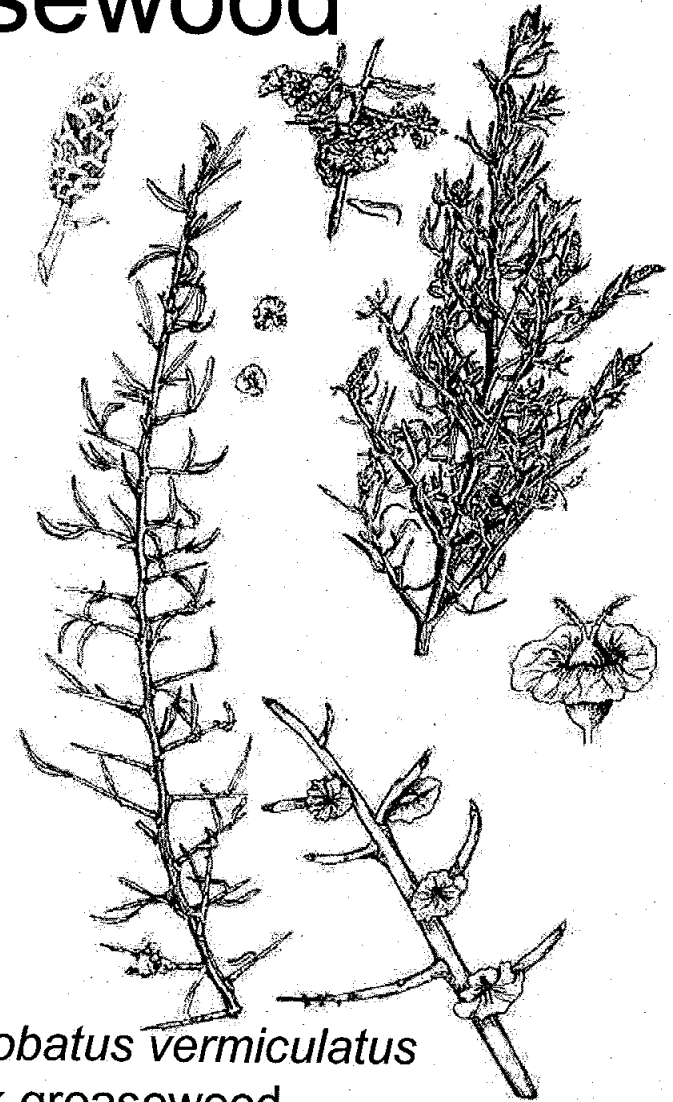
Sarcobatus vermiculatus
Black greasewood

Shortgrass Prairie Grasses
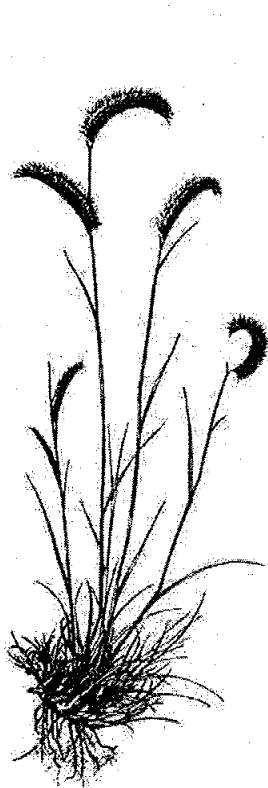
Bouteloua gracilis
Blue grama
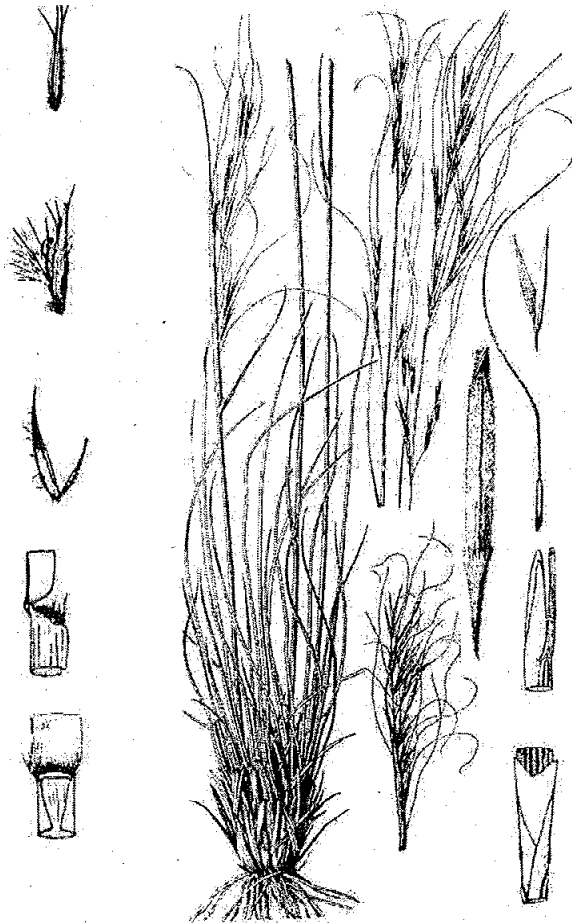
Stipa comata
Needle-and-thread

Buchloe dactyloides
Buffalo grass

Tallgrass Prairie Grasses

Andropogon gerardii
Big bluestem

Sorghastrum nutans
Indian grass
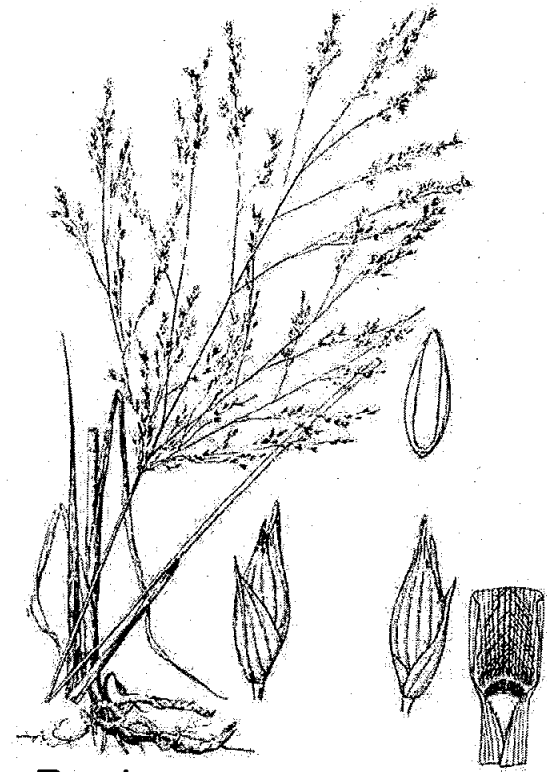
Panicum virgatum
Switchgrass

Tame Grasslands

Agropyron cristatum
Crested wheatgrass
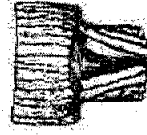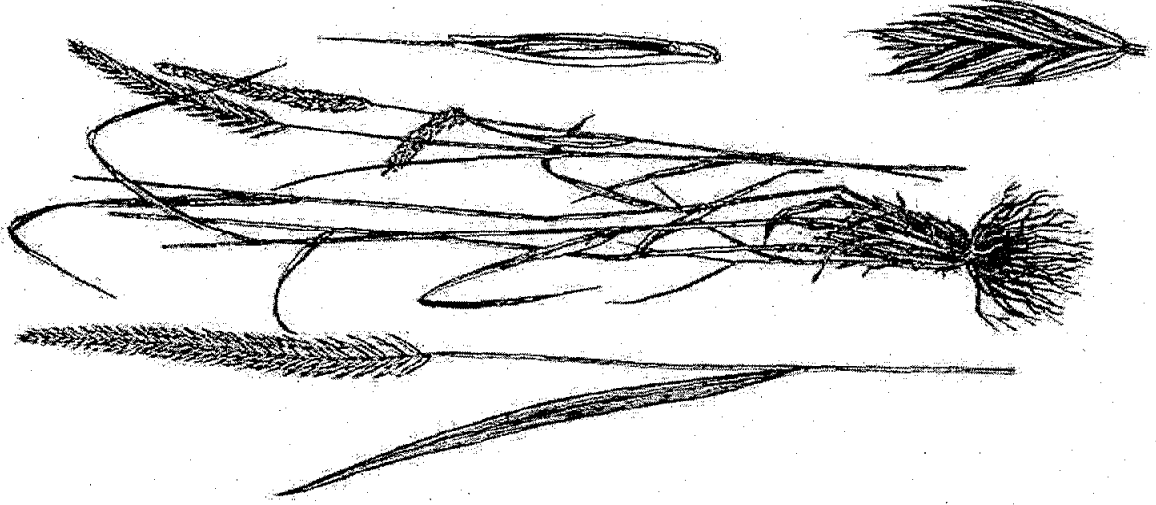
Invasive Species
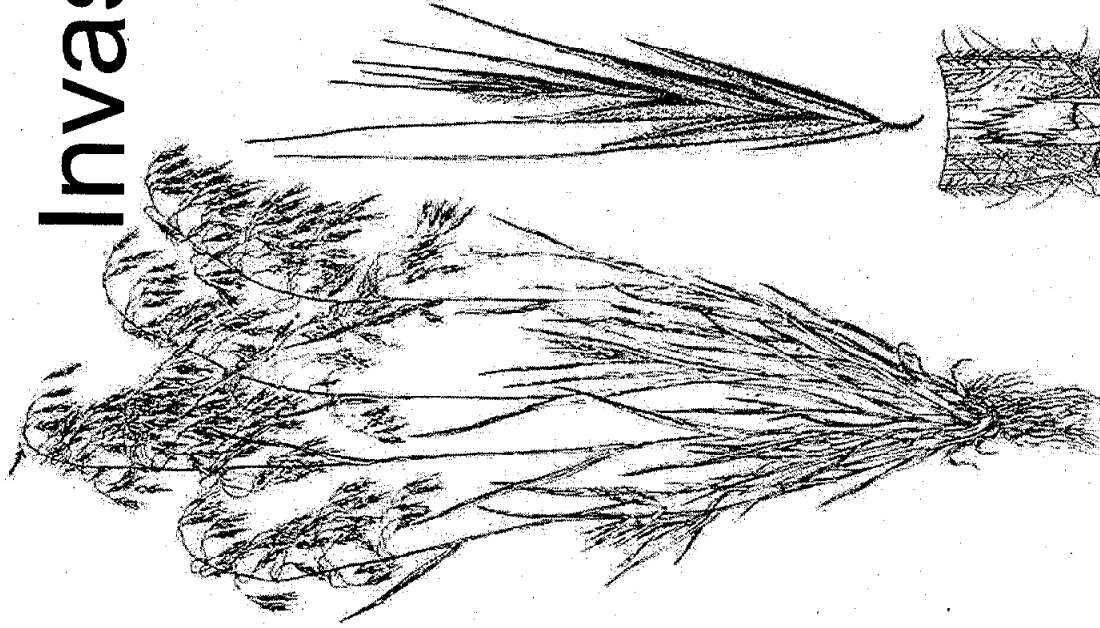
Bromus tectorum
Downy brome/Cheat grass

Poa pratensis
Kentucky blue-grass

Invasive Species
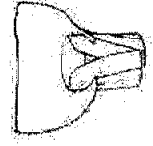
Tamarix spp.
Salt cedar

Elaeagnus angustifolia
Russian olive

Invasive Species

Cirsium spp. Thistles
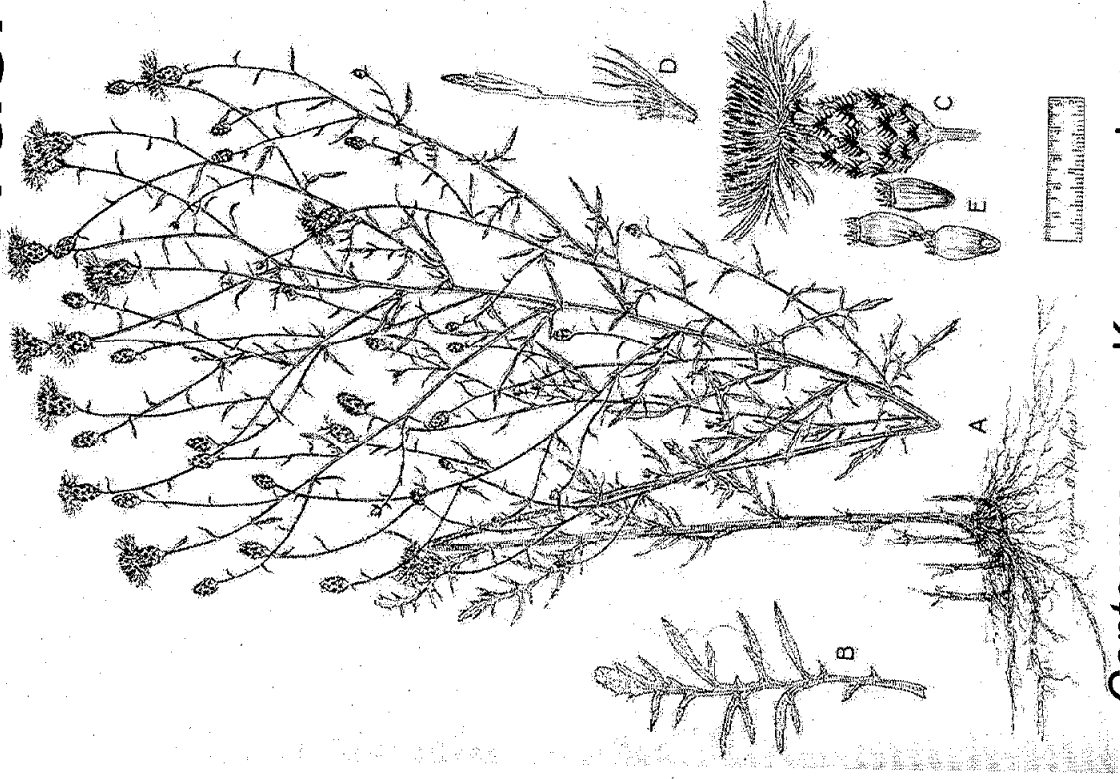
Centaurea spp. Knapweeds
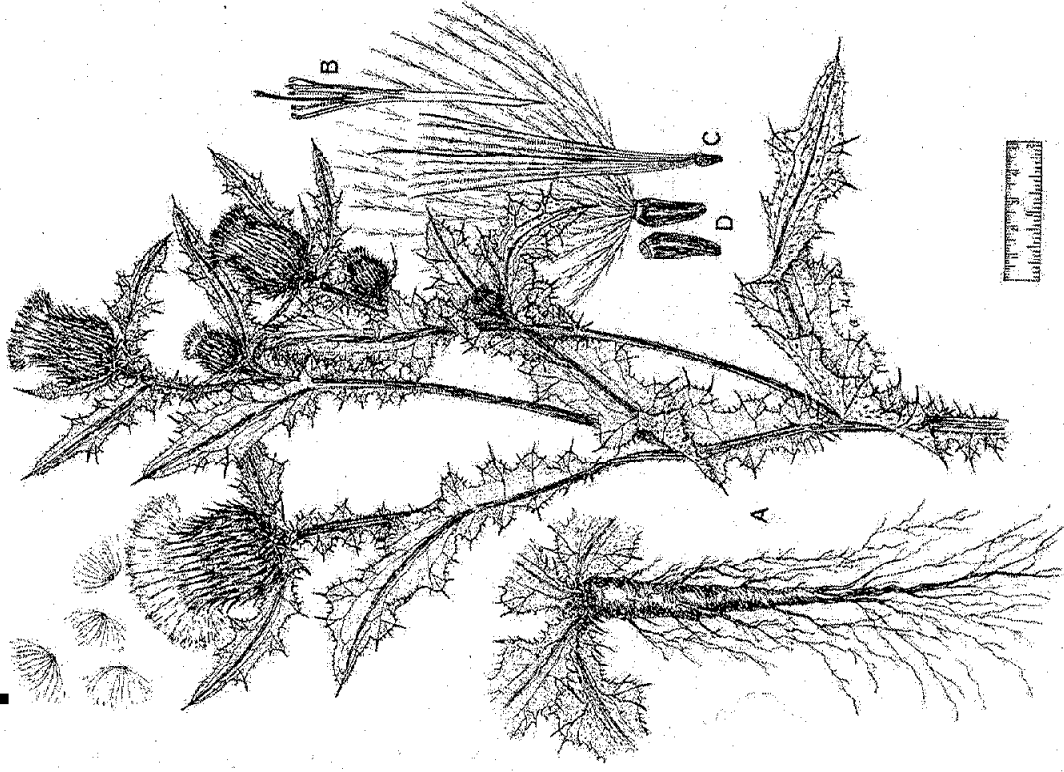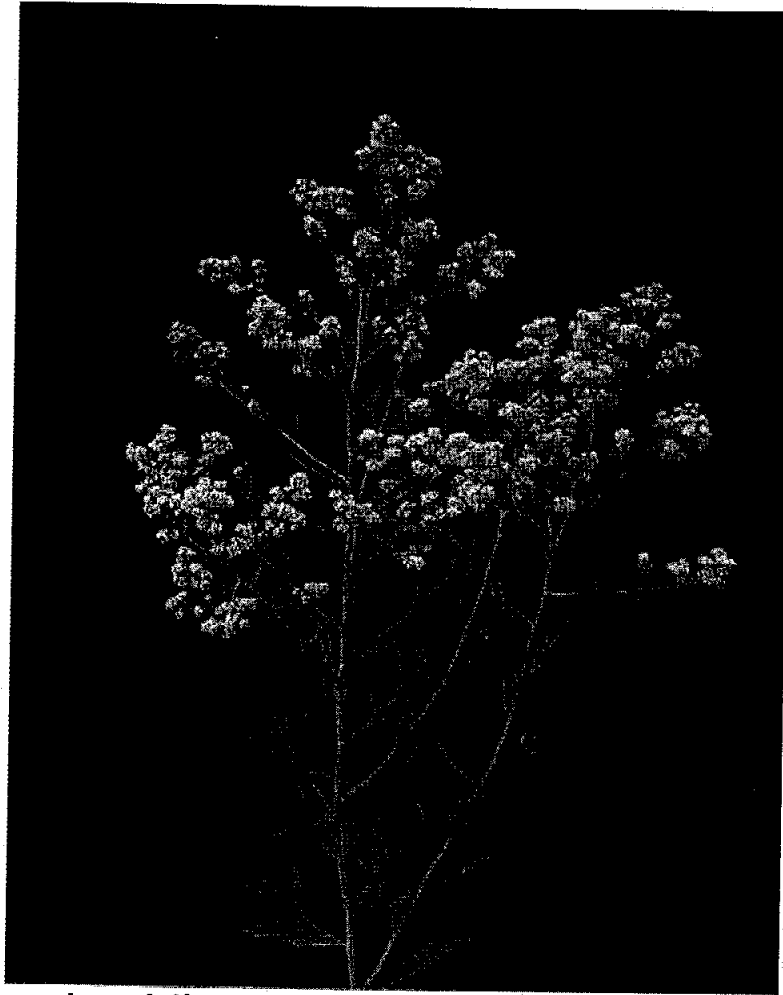
Invasive Species

Lepidium latifolium
Pepperweed/Giant Whitetop

Cardaria draba
Hoary cress
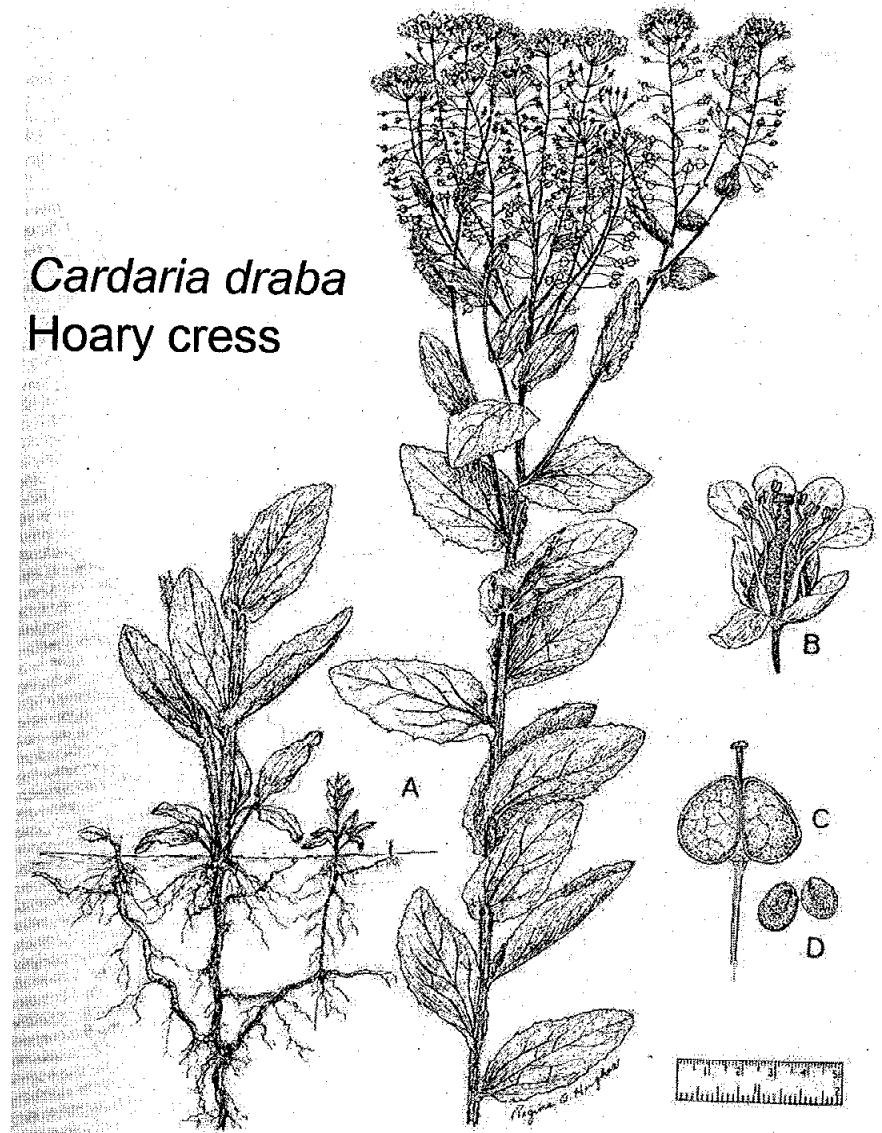
Invasive Species

Euphorbia esula
Leafy spurge
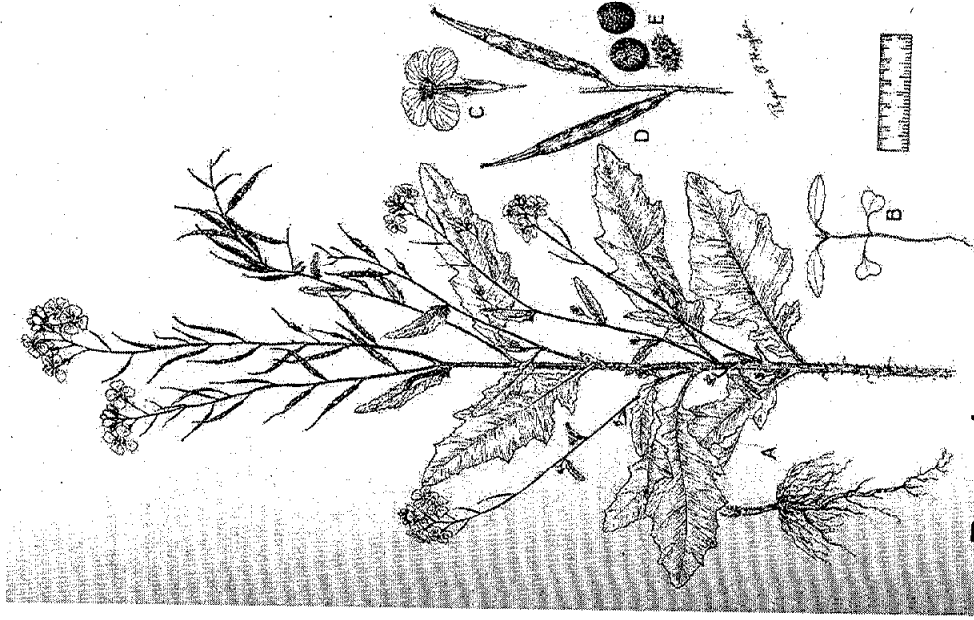
Brassica spp.
Mustards
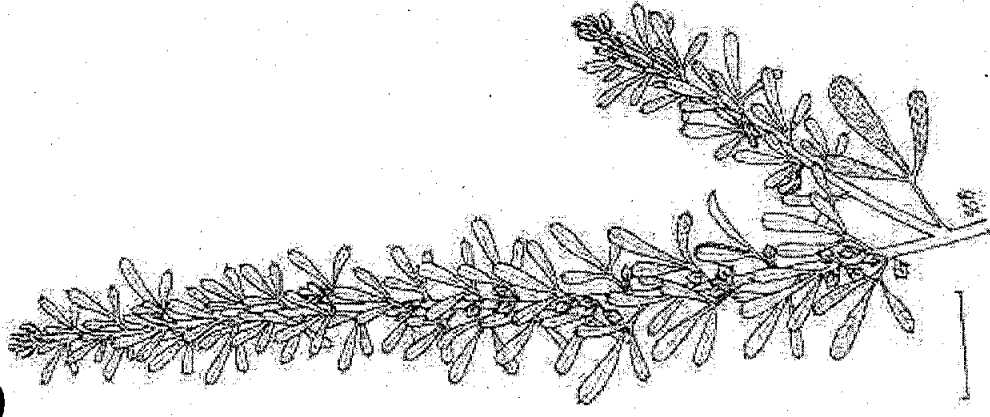
Lespedeza cuneata
Sericea lespedeza/
Chinese bush clover

Appendix H
Instructions and Examples for Moving Routes

Background - You have been provided with "working" and "backup" maps for one or more townships that will be surveyed for long-billed curlews (LBCUs). One map is a "township map" that shows certain features of the randomly selected township. This would include roads, elevation contours, a numeric township identifier, place names, and UTM coordinates (in the margins). In the upper right corner of the township map there may be handwritten numbers (e.g., p 85 or pg 69). These numbers identify the page number of the DeLorme Gazetteer we used to determine a suitable route (except for OR, we use a "Benchmark Maps" map for that state). There will be one or more pink circles (solid or open) on the township map also. These denote distinct features that are visible on the Gazetteer, and helped us to rapidly locate where on the Gazetteer the township was. You can ignore these, but it should be stressed the pink circles do not denote the start point of the route. The survey route has been drawn onto the township map with a yellow highlighter. In some cases the entire 32 km (20 mi) route could be fit onto the township map, but in other cases it could not. If it was necessary to extend the route beyond the boundaries of the township map, this will be indicated by arrows or dots or some other mark (more on this later). The routes are non-directional, meaning the terminal ends are not marked "begin" or "end." The surveyor can chose how they want to run the route.

A second map you should have is a "context map." The map shows the randomly selected township in the center, surrounded by the 8 (sometimes more) adjacent townships. Many of the same features on the township map will also be found on the context map. The purpose of the context map is to make it easier to find the general location of the route using a Gazetteer or roadmap. In cases where the survey route extends beyond the boundary of the township map, the context map shows where the route goes. We strongly suggest surveyors have a Gazetteer to refer to if their route has been drawn on the context map (when the entire route fit on the township map, the route was not drawn on the context map). The Gazetteer can be cross referenced with the context map to determine the route.

One important piece of additional information on the context maps is the stratum to which the townships belong (there are 4 strata). We have marked the context map by placing a number (1-4) in red pen near the numeric township identifier, or have denoted it using a "tic-tac-toe" grid (usually lower right corner) where the cells of the grid show the stratum of the township (the randomly selected township is in the center). The stratum to which a township belongs becomes important if you need to alter a route (more on this below). Note that the survey route is always in the same stratum. If a route crosses into a township belonging to a different stratum than the randomly selected township, then the yellow line will be discontinuous, and will resume in yellow after the route re-enters a township that is of the same stratum as the randomly selected township. For discontinuous routes, only the portion of the route denoted by yellow highlighter should be surveyed.

The final map you may have is a "state map." The state map shows the locations of the townships in relation to roads and cities. The townships are displayed in two different colors, ignore these colors, they are an artifact of earlier work and can be ignored. What matters is the

numeric identifier of the township. This numeric identifier can be cross referenced with the list of townships selected for sampling (window schedule by window v3.xls), as well as the list of townships designated as alternates (alternates_list_final.xls).

Alternate routes – Surveyors may find while running a survey route that parts of the specified route can not be completed because, for example, a road segment is private, there's a locked gate, weather conditions have made the road impassable, or the road is closed for some reason. In such cases surveyors will need to alter the route so as to complete as much of the original survey route as possible, and document the change. Below are guidelines for choosing and documenting alternate routes.

Routes were specified on the basis of these Criteria:
1. The route is 32 km (20 mi) in length, at least 10 km (6.25 mi) of the route must be in the randomly selected township, or the township is discarded.
2. The entire route should be placed in the randomly selected township, but if this is not possible the route may extend into adjacent townships belonging to the same stratum as the randomly selected township.
3. Parallel segments of a route must be separated by at least 1.6 km (1 mi).
4. Never put the route on an interstate.
5. Avoid state highways or primary roads whenever possible (this is a safety issue, there may be exceptions where such roads are acceptable if the area is remote and it is not unsafe).
6. Try to avoid roads that are likely to be impassable or where there is a high probability the surveyor will become stuck.
7. Try to avoid dead ends, where the surveyors must backtrack to continue the survey.

If a surveyor needs to draw out an alternative route, they should stick to these guidelines as closely as possible. If criterion 1 can not be met, the surveyor should check to see if they have been supplied with context and route maps for townships designated as "alternates" (see alternates_list_final.xls for a list of alternates). If they have, then the surveyor should substitute an alternate township that is nearby geographically. If several alternates are nearby, then preference should be given to those in the same stratum and same sampling window as the discard. If a 32 km (20 mi) route can not be identified that meets all of criteria 2, 3, and 4, then the route should be truncated so it is less than 32 km (20 mi). For criteria 5-7 the surveyor should factor in time constraints and safety, and use their best judgment, while keeping in mind that if criterion 1 is met the route can be less than 32 km in length.

Documenting alternate routes – Record UTM coordinates for all stops on the alternate routes on the data sheets. The alternate route should be hand drawn on the township and context maps (both the working copy and the backup copy). When surveys are completed, the annotated maps should be sent to your regional contact with completed data sheets.

Appendix I
Removal Model and Double Observer Approach

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. Auk 119(2):414-425.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117(2):393-408.

A REMOVAL MODEL FOR ESTIMATING DETECTION PROBABILITIES FROM POINT-COUNT SURVEYS

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[2]*Department of Statistics, North Carolina State University, Raleigh, North Carolina 27695, USA; and*
[3]*U.S. Geological Survey, Biological Resources Division, Patuxent Wildlife Research Center, Laurel, Maryland 20708, USA*

ABSTRACT.—Use of point-count surveys is a popular method for collecting data on abundance and distribution of birds. However, analyses of such data often ignore potential differences in detection probability. We adapted a removal model to directly estimate detection probability during point-count surveys. The model assumes that singing frequency is a major factor influencing probability of detection when birds are surveyed using point counts. This may be appropriate for surveys in which most detections are by sound. The model requires counts to be divided into several time intervals. Point counts are often conducted for 10 min, where the number of birds recorded is divided into those first observed in the first 3 min, the subsequent 2 min, and the last 5 min. We developed a maximum-likelihood estimator for the detectability of birds recorded during counts divided into those intervals. This technique can easily be adapted to point counts divided into intervals of any length. We applied this method to unlimited-radius counts conducted in Great Smoky Mountains National Park. We used model selection criteria to identify whether detection probabilities varied among species, throughout the morning, throughout the season, and among different observers. We found differences in detection probability among species. Species that sing frequently such as Winter Wren (*Troglodytes troglodytes*) and Acadian Flycatcher (*Empidonax virescens*) had high detection probabilities (~90%) and species that call infrequently such as Pileated Woodpecker (*Dryocopus pileatus*) had low detection probability (36%). We also found detection probabilities varied with the time of day for some species (e.g. thrushes) and between observers for other species. We used the same approach to estimate detection probability and density for a subset of the observations with limited-radius point counts. *Received 23 February 2000, accepted 9 October 2001.*

RESUMEN.—El muestreo mediante conteos por punto es un método popular para colectar datos sobre distribución y abundancia de aves. Sin embargo, los análisis de estos datos generalmente ignoran diferencias potenciales en la probabilidad de detección. Aquí adaptamos un modelo de remoción para estimar directamente la probabilidad de detección de aves en conteos por punto. El modelo supone que la frecuencia con que las aves cantan es un factor principal que influencia la probabilidad de detección. Esto puede ser apropiado en muestreos en donde la mayoría de las detecciones son por sonido. El modelo requiere que los conteos sean divididos en varios intervalos de tiempo. Los conteos por punto duran por lo general 10 min, donde el número de aves registradas es dividido en aquellas observadas durante los primeros 3 min, los 2 min subsecuentes y los últimos 5 min. Desarrollamos un estimador de máxima probabilidad en relación a la detectabilidad de las aves registradas durante conteos divididos en dichos intervalos. Esta técnica puede ser fácilmente adaptada a conteos por punto divididos en intervalos de cualquier duración. Aplicamos este método a conteos de radio ilimitado realizados en el Parque Nacional Great Smoky Mountains. Empleamos criterios de selección del modelo para identificar si las probabilidades de detección variaban entre especies, a lo largo de la mañana, a lo largo de las estaciones y entre diferentes observadores. Encontramos diferencias entre las especies en la probabilidad de detección. Las especies que cantan con frecuencia, como *Troglodytes troglodytes* y *Empidonax virescens*, tuvieron

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una alta probabilidad de detección (~90%), mientras que las especies que realizan pocas llamadas, cómo *Dryocopus pileatus*, tuvieron una baja probabilidad de detección (36%). Encontramos también que la probabilidad de detección varió en relación a la hora del día para algunas especies (e.g. Túrdidos) y entre observadores para otras. Empleamos el mismo procedimiento para conteos por punto de radio limitado para estimar la probabilidad de detección y la densidad en un subconjunto de las observaciones.

POINT-COUNT SURVEYS are routinely used to gather information about breeding birds. This technique involves using a standardized methodology to record all birds heard or seen during a fixed amount of time at many widely spaced count locations. This method is widely used because it is an efficient way to collect count data over a large area. However, there is considerable controversy about what inferences may be made on the basis of such data (e.g. see Burnham 1981, Johnson 1995).

Typically most investigators consider point-count surveys to represent an index of bird abundance that can be used to make comparisons between datasets (Lancia et al. 1994, Ralph et al. 1995). That requires an assumption that the probability of detection is the same for each data set being compared. For example, if two habitat types were sampled, the ratio of the counts would reflect the ratio of abundance only if the detection probabilities were the same in both habitats. Similarly, if the same location were sampled in two different years and there was a change in the number of birds counted, this change could only be interpreted as a change in population size if the detection probabilities were the same in both years. In that way, counts are often used as estimates of relative abundance.

Criticism of such analyses that use counts as an index centers on the assumption of equal detectability between datasets (Burnham 1981, Wilson and Bart 1985, Johnson 1995, Barker and Sauer 1995). Such criticism may be valid because many factors have been shown to affect detectability. For example, numbers of birds detected on point-count surveys can be affected by time of season (e.g. Best 1981, Ralph 1981, Skirvin 1981) and time of day (e.g. Robbins 1981, Skirvin 1981, Bart and Herrick 1984) presumably because of variations in singing frequency. Wilson and Bart (1985) found that the singing frequency of House Wrens (*Troglodytes aedon*) changed throughout the nesting cycle. McShea and Rappole (1997) found singing frequency for Ovenbird, Wood Thrush, and

Northern Cardinal (*Cardinalis cardinalis*) varied with distance to observer and with habitat type (fragmented vs. contiguous forest). Physical attributes of habitat such as foliage density can also affect an observer's ability to hear and identify bird song (Richards 1981). Differences in detectability are also related to skill and experience of observers (Sauer et al. 1994). Variations in detectability due to those and other factors have cast doubt on the use of counts as indexes.

One method for overcoming the assumption of equal detectability is distance sampling. It relies on the notion that detectability declines with distance from the observer (Reynolds et al. 1980, Buckland et al. 1993). The variable circular plot technique uses detection distance to estimate the detection probability and bird density from point-count surveys. However, estimating distances to all birds seen or heard can be difficult and imprecise. A method that does not require distance measures was recently developed by Nichols et al. (2000). That method estimates detection probabilities using two observers collecting data simultaneously on point-count surveys.

In point count surveys where birds are primarily detected by song, probability that a bird will be recorded during a count can be thought of as the product of two probabilities: (1) the probability the bird sings during the count, and (2) the probability the bird is detected given that it sings. Distance sampling models the decline in the second component of the probability (that a bird is detected given that it sings) with increasing distance from the observer (Reynolds et al. 1980, Buckland et al. 1993). Similarly, the double-observer approach (Nichols et al. 2000) models probability that a bird is recorded given that it could be detected by at least one observer. To be recorded by one observer, a bird must sing. Neither of those approaches deals with the first component of detection probability. We propose that if counts are separated into time intervals, we can estimate the product of both components of detec-

tion probability using the approach of a removal experiment (Moran 1951, Seber 1982). A removal experiment typically traps and removes animals from a population in discrete time periods (trap sessions). As animals are removed from the population, fewer will be available for capture in the subsequent trap sessions. The decline in numbers caught through time can then be used to estimate the initial population size.

The simplest application of this approach to point counts can be illustrated with just two time intervals of equal duration. Suppose an observer records all birds seen or heard in the interval $(0, t)$ and continues the point count, recording any additional birds detected in the interval $(t, 2t)$. At the end of the point count, we define x_1 as number of birds counted in the first time interval and x_2 as number of new birds (not detected in period 1) detected in the second time interval. The expected value of the random variable x_1 is $E(x_1) = Np_1$ where N is the total number of birds within the detection radius of the observer and p_1 is the detectability for an individual bird in the first time period. The expected value of the second random variable x_2 is $E(x_2) = N(1 - p_1)p_2$, where p_2 is the detectability in the second time period. The $(1 - p_1)$ term is needed because in order for a bird to be first counted in the second time interval, it must have been missed in the first time interval. Let us assume that detectability for the two intervals is the same (i.e. $p_1 = p_2$) because the duration of each interval is the same. Solving the above equations produces the following moment estimator for N (Zippin 1958):

$$\hat{N} = \frac{x_1{}^2}{x_1 - x_2} \qquad (1)$$

Note that the estimator can fail if $x_1 \leq x_2$ which is possible when p is small. This is a good approximation to the maximum-likelihood estimator discussed in Otis et al. (1978), which can be computed numerically using program CAPTURE (White et al. 1982).

We present this two-sample removal estimator to illustrate the approach with the simplest possible situation. In practice, we recommend using more than two intervals, which permits us to relax the assumption of equal detectability $(p_1 = p_2)$. Program CAPTURE can produce maximum-likelihood estimates for N, as well as the estimated variance of $\hat{N}$, using

model M_b (described in Otis et al. 1978 and White et al. 1982), as long as each of the time intervals is the same length. Model M_b estimates the capture probability of unmarked animals in a closed population capture-recapture experiment. Here we present a more general model that allows for the count intervals to have variable length (i.e. the detection probabilities in the different intervals need not be the same). This model is therefore a generalization of the model M_b. We illustrate the technique with several examples derived from field data.

METHODS

We developed models capable of estimating detectability when a point count is divided into three or more intervals of variable length. A common method for recording data at point counts is to separate number of birds counted into those first observed within the first 3 min, those first observed within the next 2 min, and those first observed within the final 5 min. This procedure was recommended by Ralph et al. (1995) and was originally designed to allow results from 10 min counts to be comparable with those from studies employing 3 and 5 min counts. We define x_1 as number of birds counted in the first interval, x_2 as number of birds counted in the second interval, x_3 as number of birds counted in the third interval, and $x.$ as total number of birds counted in the full 10 min $(x. = \Sigma_{j=1}^{3} x_j)$.

Estimating detectability.—We developed two estimators for detection probability, one that allows for heterogeneity (variation in the detectability within the population of birds sampled) and one that does not. We describe the most general model (M_c) that incorporates heterogeneity first because the reduced model (M) is a simplified version of this model.

First we divide the population of birds (N) within the detection radius of an observer into two groups. Group 1 is composed of the birds that are easily detected and group 2 includes those more difficult to detect. The probability that a randomly selected bird is a member of group 2 (hence the expected proportion of the population in group 2) is defined as c. We assume that all members of group 1 will be detected within the first time interval. We also define probability of failing to detect a member of group 2 within one minute as q. The expected value for number of birds detected within the first time interval of three minutes is therefore:

$$E(x_1) = N(1 - c) + Nc(1 - q^3)$$

$$= N(1 - cq^3) \qquad (2)$$

All of the members of group 1 plus some from group 2 will be detected in that interval. The probability that a bird in group 2 will be missed during the first

3 min is q^3, and the complement of this $(1 - q^3)$ is thus the probability of being detected at least once in the first interval. Similarly, the expected value of the number of birds initially detected within the next time interval (2 min) is:

$$E(x_2) = Ncq^3(1 - q^2) \qquad (3)$$

The birds first recorded during the middle interval must be missed in the first 3 min and not missed in the subsequent 2 min. Thus, these are all members of group 2. Finally, expected number of birds counted in the last 5 min of the count is:

$$E(x_3) = Ncq^5(1 - q^5) \qquad (4)$$

For a bird to be first counted in the final interval, it must be a member of group 2, and it must be missed during the first 5 min and not missed during the last 5 min. The expected total number of birds counted by the end of the full 10 min is:

$$E(x.) = N[c(1 - q^{10}) + (1 - c)]$$
$$= N(1 - cq^{10}) \qquad (5)$$

The cumulative probability of detecting a bird during the full 10 min count is thus $p = 1 - cq^{10}$. This can be described as a full multinomial distribution with probability density function:

$$f(x_1, x_2, x_3 \mid N)$$
$$= \frac{N!}{x_1! x_2! x_3! (N - x.)!} [1 - cq^3]^{x_1} [cq^3(1 - q^2)]^{x_2}$$
$$\times [cq^5(1 - q^5)]^{x_3} [cq^{10}]^{N-x.} \qquad (6)$$

However, N cannot be directly observed, so we condition on the total number of birds counted ($x.$). The conditional probability that bird y was detected within the first interval given that it was detected in the entire 10 min is:

$$\pi_1 = P(y \in x_1 \mid y \in x.) = \frac{1 - cq^3}{1 - cq^{10}} \qquad (7)$$

The conditional probability of first detecting bird y within the second interval given that it was detected in the entire 10 min is:

$$\pi_2 = P(y \in x_2 \mid y \in x.) = \frac{cq^3(1 - q^2)}{1 - cq^{10}} \qquad (8)$$

Finally the conditional probability of first detecting bird y in the third interval given that it was detected in the entire 10 min is:

$$\pi_3 = P(y \in x_3 \mid y \in x.) = \frac{cq^5(1 - q^5)}{1 - cq^{10}} \qquad (9)$$

Therefore the conditional multinomial has the probability density function:

$$f(x_1, x_2, x_3 \mid x.) = \frac{x.!}{x_1! x_2! x_3!} (\pi_1)^{x_1} (\pi_2)^{x_2} (\pi_3)^{x_3} \qquad (10)$$

Now we can find the estimates of c and q that maximize the following likelihood function:

$$L(c, q \mid x_1, x_2, x_3)$$
$$\propto \left[\frac{1 - cq^3}{1 - cq^{10}}\right]^{x_1} \left[\frac{cq^3(1 - q^2)}{1 - cq^{10}}\right]^{x_2} \left[\frac{cq^5(1 - q^5)}{1 - cq^{10}}\right]^{x_3} \qquad (11)$$

We used program SURVIV (White 1983) to find the values of c and q that maximized the above likelihood function. SURVIV also computed associated estimates of the variances and covariance of c and q. We then reparameterized the SURVIV model to estimate the total detectability for the full 10 min ($\hat{p}$) and its associated standard error. This parameter, p, incorporates both group membership and the group detection probabilities and specifies the probability that an individual bird randomly selected from N is detected during the 10 min sampling period ($p = 1 - cq^{10}$).

This model represents a modified special case of more general mixture models in which detectability of members of group 1 is estimated (not assumed to be one, as is done here). Norris and Pollock (1996) and Pledger (2000) fit full two-point mixture models to capture–recapture and removal data for closed populations. Because counts were divided into three intervals in our example, we were unable to fit those full two-point mixture models. At least four intervals are necessary to use the full two-point mixture models.

The model described here represents the most general (fully parameterized) model possible under this sampling design. This model can then be tested against more specific (reduced parameter) models. One such model constrains c to be equal to 1 and thus represents a model that does not attempt to incorporate heterogeneity (i.e. all birds are members of group 2). In addition, when different datasets are compared, the most general model will treat the estimates of c and q differently for each dataset. A more specific model will constrain the estimates of both c and q to be equal for both datasets ($c_1 = c_2$; $q_1 = q_2$). We used Akaike's Information Criterion (AIC; Burnham and Anderson 1998) for model selection and chose the model that most parsimoniously fit the data (i.e. model with minimum AIC).

Estimating density.—Once detection probability is estimated with either model, abundance can then be estimated as:

$$\hat{N} = \frac{x.}{\hat{p}} \qquad (12)$$

When limited-radius point counts are used, this estimate of abundance can be used to estimate density simply as:

$$\hat{D} = \frac{\hat{N}}{A} \qquad (13)$$

where A is the total area sampled (sum of the areas within each limited-radius count). Assuming that the counts $(x.)$ are from a binomial distribution and independent of $\hat{p}$, an estimate of the variance of density at the sampled points is (after Nichols et al. 2000):

$$\widehat{VAR}(\hat{D}) = \frac{(x.)^2\widehat{VAR}(\hat{p})}{A^2\hat{p}^4} + \frac{(x.)(1-\hat{p})}{A^2\hat{p}^2} \qquad (14)$$

If the estimated density were to be extrapolated to a defined area from which counts were sampled, a more formal estimate of the variance of density should include the variance associated with differences in counts over the sampled locations within the larger space (e.g. Thompson 1992). For the purposes of illustration in this paper, we will only consider the sampling variance represented by Eq. 14.

Model assumptions are as follows:

1. There is no change in the population of birds within the detection radius during the point count (i.e. the population is closed).
2. There is no double-counting of individuals.
3. All members of group 1 are detected in the first interval.
4. All members of group 2 that have not yet been detected have a constant per minute probability of being detected.
5. If counts with limited-radius are used, observers accurately assign birds to within or beyond the radius used.

Field data.—We applied this approach to data collected in Great Smoky Mountains National Park from 1993 to 1995. We conducted counts at 258 locations up to three times within each year for a total of 1,221 point counts (some locations were not surveyed in every year). Surveys were located in closed-canopy deciduous hardwood forests. In those areas with high canopy (20–30 m) and dense vegetation, most detections were recorded by ear. Our population of interest was therefore vocalizing birds (i.e. birds with non-negligible probability of vocalizing during the period of the point count). For the four songbird species to be discussed at length, Ovenbird, Black-throated Green Warbler, Red-eyed Vireo, and Black-throated Blue Warbler (see Appendix for scientific names), we recorded singing males, ignoring nonsong vocalizations. For each count, the total number of birds counted was divided into those detected within the first 3 min, the subsequent 2 min, and the final 5 min as described above. In addition, birds were recorded as within 50 m from the observer or beyond 50 m.

Unlimited-radius counts.—For the 15 most frequently detected species, we fit the data to four models. Model M^s_c, the most general model, estimated sepa-

rate parameters for each species and included heterogeneity (using the term c described above). Model M_c allowed heterogeneity among individuals but did not fit separate parameters for the different species. Model M^s fit the data separately for the different species, but had the constraint $c = 1$. Thus this model did not incorporate heterogeneity. And model M, with only a single parameter, did not account for heterogeneity ($c = 1$), nor did it fit different estimates of q for each species.

For each of the four most frequently recorded species (Ovenbird, Black-throated Green Warbler, Red-eyed Vireo, and Black-throated Blue Warbler) we examined how temporal changes in bird activity influenced detectability. We compared detectability between those points conducted early in the morning (sunrise to 0745 EST; 610 points) with those conducted late in the morning (0746 to 1000; 611 points). If birds sing more frequently in early morning, we would expect them to have higher detectabilities at that time. In addition to the four species above, we also examined detection probability using combined data for Wood Thrush and Veery. Thrushes sing more frequently early in the morning than later in the day. Therefore they should have a higher detection probability earlier in the morning. We tested each of four models with data from the four most common species and the combined data for the thrushes. Model M^t_c incorporated heterogeneity and estimated different parameters for early morning and late morning. Model M_c incorporated heterogeneity but did not distinguish between early and late morning counts. Model M^t estimated different parameters for early and late morning, but did not incorporate heterogeneity. And model M did not incorporate heterogeneity or distinguish between early and late morning.

We also compared detectability between counts conducted at different times during the breeding season. Different bird species may have different peaks in singing frequency due to differences in nesting behavior, which will change their detectability. Species that nest early and attempt only one brood may have reduced singing frequencies by late spring compared to species that raise multiple broods. We separated the counts conducted on or before 20 May (early spring; 563 points), and those conducted after 20 May (late spring; 658 points). We fit four models to examine seasonal changes in detectability. Model M^p_c incorporated heterogeneity and estimated different parameters for early and late spring. Model M_c incorporated heterogeneity but did not distinguish between early and late spring. Model M^p estimated different parameters for the early and late spring, but did not incorporate heterogeneity. And model M did not incorporate heterogeneity or distinguish between early and late spring.

Observer variability related to differences in skill or hearing acuity is another potential factor affecting

detection probability. We compared detectability using the three observers for which we had the largest number of counts (observer 1 conducted 255 counts, observer 2 conducted 200, and observer 3 conducted 178). Again we fit four models for data from the four most common species. Model M^o_c incorporated heterogeneity and estimated different parameters for the different observers. Model M_c incorporated heterogeneity but did not distinguish between observers. Model M^o estimated different parameters for each observer, but did not incorporate heterogeneity. And model M did not incorporate heterogeneity or distinguish between observers.

The analyses described above only address issues of detection probability. For those analyses, each point count was considered an independent trial with respect to the estimate of detection probability, and unlimited-radius counts were used. Multiple counts were conducted at the same locations so we were not able to estimate abundance or density.

Limited-radius counts.—To estimate abundance and density, we restricted the analysis to two visits to each location in 1994 (155 locations). Each visit was treated as a separate sampling of abundance for the 155 counts. Only birds detected within 50 m of the observer were included because an estimate of density requires a measurement of the area sampled. Counts were separated by approximately two weeks between the first and second visit to each point location. It therefore seemed reasonable to expect the true abundance (and density) to be the same for those two visits. The same four species were used in this analysis. For each species, model selection was performed to choose between a model that incorporated heterogeneity (M_c) and a model that did not (M) as described above. Using the estimated detection probability ($\hat{p}$) from the most parsimonious model, we estimated abundance and density for each visit. We compared estimated density between visits for each species by estimating difference between densities for the two periods.

RESULTS

For the 15 most frequently detected species, the most parsimonious model was M^s_c (AIC values: $M^s_c = 249.5$, $M_c = 370.3$, $M^s = 570.7$, and $M = 728.8$). Thus, there was strong evidence of differences in estimated detectability for different species (Fig. 1). Also, heterogeneity appeared to be an important component of the detectability requiring an estimate for parameter c for each species.

We did not find evidence of a change in detection probability at different times of the morning for three species. Model M_c received the most support for the data for Ovenbird,
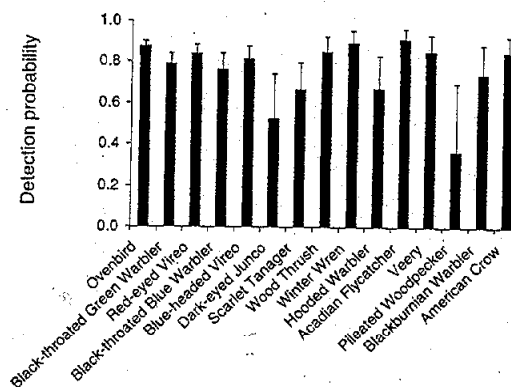

FIG. 1. Estimated detection probability during unlimited-radius counts for the 15 most frequently encountered species, ordered from most common (left) to least common (right). Error bars represent one estimated standard error. See Appendix for scientific names and count data.

Black-throated Green Warbler, and Red-eyed Vireo. However, model M^t_c received the most support for Black-throated Blue Warbler and the combined data for thrushes (Wood Thrush and Veery). Estimated detection probability appeared to decrease later in the morning for those species (Table 1). We did not find evidence of an influence of time of season on detectability for three of the four species tested. Model M_c received the most support for the data for Ovenbird, Black-throated Green Warbler, and Black-throated Blue Warbler. Model M^b_c was best supported for Red-eyed Vireo; however the estimated detection probability for early spring was only slightly lower than that for late spring (Table 2).

We found evidence of different detection probabilities for different observers for two species (model M^o_c received the most support). Observer 1 had higher estimated detectability than observers 2 and 3 for Ovenbird and Black-throated Green Warbler. Detectability for Red-eyed Vireo and Black-throated Blue Warbler did not appear to vary among observers (model M received the most support; Table 3). When testing Black-throated Blue Warbler, we were unable to estimate the parameters for each observer under model M^o_c due to the small number of detections during the middle time interval by observer 2. Model M_c was best supported when observers 1 and 3 were compared, suggesting no difference in estimated detection probability for these two observers.

TABLE 1. Detection probabilities during unlimited-radius counts conducted in early (at or before 0745) and late (after 0745) morning. AIC for model that received the most support is underlined. Selection of model M^t_c indicates different estimated detection probabilities for early and late morning. See text for description of models.

Time of count	Counts[a]			AIC of models				$\hat{p}$ (SE)	
	x^1	x^2	x^3	M^t_c	M_c	M^t	M	Model M^t_c	Model M_c
Ovenbird									
Early morning	1,003	170	233	35.5	32.9	115.6	114.4	0.90 (0.03)	0.87 (0.03)
Late morning	836	134	216					0.83 (0.08)	—
Black-throated Green Warbler									
Early morning	591	123	403	34.7	31.4	89.1	87.5	0.80 (0.07)	0.79 (0.05)
Late morning	631	118	202					0.78 (0.08)	—
Red-eyed Vireo									
Early morning	502	101	149	33.6	30.5	63.5	62.5	0.86 (0.05)	0.84 (0.04)
Late morning	426	90	143					0.81 (0.07)	—
Black-throated Blue Warbler									
Early morning	287	74	100	32.5	35.2	69.3	67.6	0.87 (0.05)	0.76 (0.08)
Late morning	405	65	140					0.51 (0.29)	—
Thrush species (Wood Thrush and Veery)									
Early morning	376	66	89	31.3	33.6	50.7	55.7	0.90 (0.04)	0.85 (0.05)
Late morning	199	41	74					0.72 (0.17)	—

[a] x_i is number of birds first detected in the ith interval.

Estimating density.—Using the subset of independent limited-radius counts, the best supported model for Ovenbird and Black-throated Green Warbler included heterogeneity (model M_c) for both visits. The selected model for Black-throated Blue Warbler did not include heterogeneity (model M) for either visit. And the best supported model for Red-eyed Vireo was M for the first visit and M_c for the second visit. Esti-

mates of detection probability ranged from 0.81 (0.19 $\widehat{SE}$) for Red-eyed Vireo to 0.97 (0.02 $\widehat{SE}$) for Black-throated Blue Warbler (Table 4). And the estimates of density ranged from 0.49 (0.02 $\widehat{SE}$) singing birds per hectare for Black-throated Blue Warbler to 1.93 (0.16 $\widehat{SE}$) singing birds per hectare for Ovenbird. Estimates of the difference in density between visits ($\Delta\hat{D}$) ranged from 0.04 birds per hectare for Black-throated Blue War-

TABLE 2. Detection probabilities during unlimited-radius counts conducted in early (on or before 20 May) and late (after 20 May) spring. AIC for model that received the most support is underlined. Selection of model M^b_c indicates different estimated detection probabilities for early and late spring. See text for description of models.

Time of count	Counts[a]			AIC of models				$\hat{p}$ (SE)	
	x_1	x_2	x_3	M^b_c	M_c	M^b	M	Model M^b_c	Model M_c
Ovenbird									
Early spring	927	163	223	35.5	32.8	116.3	114.3	0.90 (0.03)	0.87 (0.03)
Late spring	912	141	226					0.84 (0.05)	—
Black-throated Green Warbler									
Early spring	629	131	209	34.7	31.4	89.4	87.5	0.81 (0.06)	0.79 (0.05)
Late spring	593	110	194					0.76 (0.09)	—
Red-eyed Vireo									
Early spring	443	103	159	33.6	35.0	63.7	67.0	0.82 (0.06)	0.84 (0.04)
Late spring	485	88	133					0.85 (0.06)	—
Black-throated Blue Warbler									
Early spring	289	56	109	32.5	29.8	63.2	62.1	0.65 (0.20)	0.76 (0.08)
Late spring	403	83	131					0.82 (0.07)	—

[a] x_i is number of birds first detected in the ith interval.

TABLE 3. Detection probabilities during unlimited-radius counts conducted by different observers. AIC for model that received the most support is underlined. Selection of model M^o_c indicates different estimated detection probabilities for different observers. See text for description of models.

Observer	Counts[a]			AIC of models				$\hat{p}$ (SE)	
	x_1	x_2	x_3	M^o_c	M_c	M^o	M	Model M^o_c	Model M_c
Ovenbird									
Observer 1	451	57	83	<u>47.2</u>	53.6	92.4	102.8	0.90 (0.05)	0.87 (0.04)
Observer 2	319	49	78					0.84 (0.09)	—
Observer 3	261	56	83					0.85 (0.07)	—
Black-throated Green Warbler									
Observer 1	295	46	62	<u>45.4</u>	51.6	60.1	71.0	0.91 (0.05)	0.86 (0.05)
Observer 2	187	44	65					0.84 (0.08)	—
Observer 3	146	37	59					0.80 (0.12)	—
Red-eyed Vireo									
Observer 1	218	27	54	43.8	<u>42.8</u>	67.4	67.7	0.68 (0.29)	0.80 (0.08)
Observer 2	151	32	49					0.83 (0.11)	—
Observer 3	137	31	47					0.83 (0.11)	—
Black-throated Blue Warbler[b]									
Observer 1	153	21	36	28.0	<u>25.7</u>	42.0	41.8	0.81 (0.17)	0.79 (0.13)
Observer 3	123	22	39					0.76 (0.21)	—

[a] x_i is number of birds first detected in the ith interval.
[b] Models could not estimate separate parameters for observer 2.

bler to 0.39 birds per hectare for Red-eyed Vireo. The associated 95% confidence intervals for $\Delta\hat{D}$ included zero for all species.

DISCUSSION

Application of a removal model to point count surveys divided into time intervals offers a promising new approach for estimating detectability. Detectability estimates allow for comparisons among datasets without having to resort to using counts as an index of abundance. One strength of that procedure is that it can be applied to existing data as we have done here. In addition, it may be incorporated into future studies with no additional cost and without much additional training.

TABLE 4. Estimation of density for two visits to the same count locations in 1994. AIC for model that received the most support is underlined. The low-AIC model was used to estimate p and D. Confidence interval (95%) for estimated difference in density, $\Delta\hat{D}$, included zero for all species.

Visit	Counts[a]			AIC		$\hat{p}$ (SE)	$\hat{D}$ (SE) Birds ha^{-1}	$\Delta\hat{D}$ (95% CI) Birds ha^{-1}
	x_1	x_2	x_3	M_c	M			
Ovenbird								
First visit	141	29	39	14	16	0.89 (0.07)	1.93 (0.16)	0.12 (−0.27, 0.51)
Second visit	152	23	29	<u>14</u>	17	0.93 (0.06)	1.81 (0.11)	—
Black-throated Green Warbler								
First visit	96	18	26	14	15	0.87 (0.11)	1.32 (0.17)	0.26 (−0.14, 0.66)
Second visit	118	26	32	<u>14</u>	14	0.91 (0.06)	1.58 (0.11)	—
Red-eyed Vireo								
First visit	64	19	25	13	12	0.92 (0.03)	0.96 (0.04)	0.39 (−0.23, 1.01)
Second visit	94	15	25	<u>13</u>	17	0.81 (0.19)	1.35 (0.31)	—
Black-throated Blue Warbler								
First visit	43	11	9	12	10	0.97 (0.02)	0.53 (0.01)	0.04 (−0.01, 0.10)
Second visit	35	9	12	12	<u>10</u>	0.93 (0.04)	0.49 (0.02)	—

[a] x_i is number of birds first detected in the ith interval.

Many of the differences we observed in detectability were probably due to differences in singing frequency. The species with the highest estimated detectabilities were Winter Wren ($\hat{p}$ = 0.89 ± 0.06 $\widehat{SE}$) and Acadian Flycatcher ($\hat{p}$ = 0.91 ± 0.05 $\widehat{SE}$). Winter Wrens and Acadian Flycatchers sing frequently making them easy to detect on point count surveys. Conversely, Pileated Woodpeckers, which give loud but infrequent vocalizations, had the lowest detectability estimate ($\hat{p}$ = 0.36 ± 0.33 $\widehat{SE}$) among the 15 most frequently detected species. We also found a decrease in detection probability for thrushes from early morning to late morning counts (Table 1), probably due to a tendency for thrushes to sing most frequently early in the morning and only sporadically later in the day.

We found differences in the detection probabilities between observers for certain species. That may reflect differences in hearing abilities among observers. Different observers may have different sensitivities to songs of particular species, allowing them to detect a greater proportion of those species than other observers. Observers may also show favoritism to some species, recording those species preferentially when uncertain about identification (Bart 1985). Detectability of a species declines with increasing density of that species, and that may be especially true when observers are recording multiple species at the same time (Scott and Ramsey 1981, Bart and Shoultz 1984). The observers in our field study recorded all individuals of all species detected. The average number of detections per point count was high (11.8 birds) and observers' abilities to discriminate individuals may have been compromised on some counts. We found that observers often focused their attention on one species at a time to help them discriminate individuals of that species. If observers dedicate different amounts of effort (time focused on one species) for different species, that could lead to observer differences in detectability.

In our examples, we have conducted separate modeling efforts for individual species. We have done so because that is the traditional approach to estimating parameters of animal populations. Species differences are often suspected to be so large as to preclude simultaneous modeling of multiple species. However, as noted by Nichols et al. (2000), it may be reasonable to estimate detectability by groups of species expected a priori to exhibit similar detection probabilities. Similarly, we estimated the influence on detectability separately for each of the factors discussed (time of day, time of season, and observer). Our approach could be applied to a more general model capable of examining multiple factors simultaneously and detecting interactions among them (for example, an interaction between time of day and time of season). However, such an analysis would require a larger data set than we used here. Parsimonious modeling of detection probability might include multiple species with the same detection probabilities, observer differences with parallel effects for different species, and possibly interactions between species, observers, and other factors. Such modeling of multiple species and interaction among factors can be readily implemented using the general modeling framework that we have presented and should be an area of active research.

The estimates for density were developed from a small data set (155 limited-radius counts). The two visits to each count location should represent two samples from the same population. Therefore we did not expect the estimates of density to differ between visits. Indeed, although estimates of density differed among species, they did not differ within species for the two visits. For the purposes of this article, we only dealt with sampling variance at the actual locations. This was adequate for our tests because we were testing estimated density for two visits to the same count locations. We did not have independent estimates of density (e.g. spot-map data or nest locations) with which we could compare these density estimates. Future work should attempt to compare estimates generated from this removal sampling procedure to known density and to results of other estimation procedures (e.g. see Tarvin et al. 1998).

Model assumptions.—Assumption 1: there is no change in the population of birds within the detection radius during the point count. This assumption of closure may not be met for some species during a 10 min count. This should be less of a problem for small breeding songbirds, such as Wood Warblers, with their relatively small territories and high singing rates. However for larger ranging species like Pileated Woodpecker and American Crow, this assumption is more likely to be violated. The model

will work equally well for point counts of shorter duration (e.g. 5 min) that are more likely to meet the assumption of closure, provided the count is divided into three or more intervals.

Assumption 2: there is no double-counting of individuals. The somewhat long duration of the point counts used in this analysis (10 min) may lead to violation of this assumption. However, observers were trained to be conservative in this regard. Similarly, there may have been identification errors. Such phantom detections would result in recording species that are not present and inflating the number of individuals recorded for some species that are present (see Bart and Schoultz 1984, Bart 1985). Whereas violations of assumptions 1 and 2 may present problems for this analysis, they are not unique to this method; they are also necessary for virtually any analysis of point-count data, even naïve analyses that do not adjust for detectability.

Assumptions 3 and 4: all members of group 1 are detected in the first interval; all members of group 2 have a constant per minute probability of being detected. These two assumptions are likely to be violated to some degree. This modeling device should not be interpreted literally. With the available count data divided into three time intervals, this was the best way we could address the issue of heterogeneity of detection probability. Our procedure included model selection using AIC to choose between models with one group ($c = 1$) and models with two groups. The critical parameter when estimating abundance in the face of heterogeneous detection probabilities among individuals is the coefficient of variation of the distribution of detection probabilities (Carothers 1973). Carothers (1973) was the first to note that this variation could be modeled adequately using a two-point distribution, and Pledger (2000) successfully exploited this approach as well. Specifically, Pledger (2000) demonstrated that using a model with two groups (each with a homogenous detection probability) was adequate to provide an unbiased estimate of population size even when the population was composed of many such groups. Our model constrained group 1 to have a detection probability of one because our counts were only divided into three intervals.

Another way in which these assumptions may be violated is if the detection probability varies through time during the count. For example, even if there were two uniform groups, members of group 2 could have higher detectability in the fourth minute than in the eighth minute, although it may not be easy to develop a plausible biological story for such variation, especially with likely variation in starting times of different point counts. Even when assumptions such as these are likely to be violated, use of this model-based approach is likely to be far more robust than index methods that assume counts to be a constant fraction of the sampled populations (e.g. see Nichols and Pollock 1983).

Assumption 5: if counts with limited-radius are used, observers accurately assign birds to within or beyond the radius used. In order to estimate density, some measure of area sampled is necessary. In this study, observers were trained to estimate distance to birds and assign each detection to within or beyond 50 m from the observer. Even with training and experience, it is often difficult to estimate distances to birds on the basis of hearing songs. This assumption is also required for distance sampling and virtually any method of density estimation.

Recommendations and future work.—We constructed this particular model with three time intervals because this count procedure was recommended by Ralph et al. (1995). We hope this will facilitate its use in analyzing existing data. However, our model is flexible enough to accommodate data collected in other ways. We recommend that future surveys be designed to include four or more time intervals of equal duration. That would allow the use of full two-point mixture models and would simplify the mathematics (see Pledger 2000). For example, a 10 min point count divided into five intervals of 2 min each would allow use of the more general model and goodness-of-fit tests for all three models (M, M_c, and the full two-point mixture model). However, to avoid violation of assumptions 1 and 2, short counts may be preferable in some instances. Perhaps a 5 min count divided into 1 min intervals would be appropriate.

In addition, combining the removal approach with other current methods may provide improved estimates of detectability and density. For example, a procedure that combines removal sampling with distance sampling would al-

low estimation of two separate components of detectability: probability a bird sings and probability song is detected as a function of distance form observer. Similarly, combining the removal approach with double-observer sampling could also address two components of detectability: probability a bird sings and probability a song is detected by at least one observer. Perhaps all three techniques could be combined into one study with known density to evaluate the merits of each method and the various combinations thereof.

ACKNOWLEDGMENTS

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APPENDIX. Scientific names and total counts for species in Figure 1.

Common name	Scientific name	Counts[a]		
		x_1	x_2	x_3
Ovenbird	Seiurus aurocapillus	1,839	304	449
Black-throated Green Warbler	Dendroica virens	1,222	241	403
Red-eyed Vireo	Vireo olivaceus	928	191	292
Black-throated Blue Warbler	Dendroica caerulescens	692	139	240
Blue-headed Vireo	Vireo solitarius	645	129	207
Dark-eyed Junco	Junco hyemalis	425	90	188
Scarlet Tanager	Piranga olivacea	392	98	182
Wood Thrush	Hylocichla mustelina	340	59	91
Winter Wren	Troglodytes troglodytes	351	49	71
Hooded Warbler	Wilsonia citrina	233	62	114
Acadian Flycatcher	Empidonax virescens	257	46	60
Veery	Catharus fuscescens	235	48	72
Pileated Woodpecker	Dryocopus pileatus	144	53	116
Blackburnian Warbler	Dendroica fusca	169	45	77
American Crow	Corvus brachyrhynchos	159	51	71
Other species		1,162	332	723

[a] x_i is number of birds detected in the ith interval.

A DOUBLE-OBSERVER APPROACH FOR ESTIMATING DETECTION PROBABILITY AND ABUNDANCE FROM POINT COUNTS

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ABSTRACT.—Although point counts are frequently used in ornithological studies, basic assumptions about detection probabilities often are untested. We apply a double-observer approach developed to estimate detection probabilities for aerial surveys (Cook and Jacobson 1979) to avian point counts. At each point count, a designated "primary" observer indicates to another ("secondary") observer all birds detected. The secondary observer records all detections of the primary observer as well as any birds not detected by the primary observer. Observers alternate primary and secondary roles during the course of the survey. The approach permits estimation of observer-specific detection probabilities and bird abundance. We developed a set of models that incorporate different assumptions about sources of variation (e.g. observer, bird species) in detection probability. Seventeen field trials were conducted, and models were fit to the resulting data using program SURVIV. Single-observer point counts generally miss varying proportions of the birds actually present, and observer and bird species were found to be relevant sources of variation in detection probabilities. Overall detection probabilities (probability of being detected by at least one of the two observers) estimated using the double-observer approach were very high (>0.95), yielding precise estimates of avian abundance. We consider problems with the approach and recommend possible solutions, including restriction of the approach to fixed-radius counts to reduce the effect of variation in the effective radius of detection among various observers and to provide a basis for using spatial sampling to estimate bird abundance on large areas of interest. We believe that most questions meriting the effort required to carry out point counts also merit serious attempts to estimate detection probabilities associated with the counts. The double-observer approach is a method that can be used for this purpose. *Received 16 November 1998, accepted 1 October 1999.*

A BEWILDERING VARIETY of methods exists for assessing animal abundance (e.g. Ralph and Scott 1981, Seber 1982, Lancia et al. 1994). However, all methods involve the collection of some sort of count statistic. Count statistics are as varied as the methods by which they are obtained and include number of birds seen and heard at a point-count location, number of ungulates seen while walking a line transect, number of small mammals caught on a trapping grid, number of kangaroos seen from an airplane flying an aerial transect, and number of tigers photographed by camera traps. The relationship between a count statistic and the quantity of interest, abundance or population size, can be written as follows (see Barker and Sauer 1992, Nichols 1992, Lancia et al. 1994):

$$E(C_i) = N_i p_i, \qquad (1)$$

where C_i denotes the count, N_i the true abundance, and p_i the detection probability, all associated with time and location i.

Two basic approaches use count statistics to draw inferences about animal abundance and changes in abundance over time (Lancia et al. 1994, Wilson et al. 1996). One approach is to collect the count data in a manner that permits estimation of the associated detection probability. Such estimates then permit direct estimation of population size:

$$\hat{N}_i = \frac{C_i}{\hat{p}_i}, \qquad (2)$$

where the hats denote estimates. Resulting estimates of population size can be used to draw inferences about changes in abundance over time and/or space. If the estimates of detection

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probabilities provide strong evidence that they are similar for different times or locations, then the count statistics themselves can be used to draw inferences about differences in abundance (Skalski and Robson 1992).

The other approach is not to estimate detection probability, but to use standardized methods to obtain the count statistic in the hope that detection probabilities will be similar for the times or places for which abundance comparisons are to be made (i.e. that $p_i = p$ for all i in the comparison). Under this approach, the count statistic is viewed as an index to abundance (Conroy 1996). In some cases, the collection of index statistics is accompanied by the measurement of some small number of covariates (e.g. weather variables) that are thought to influence detection probability. Under the assumption that these covariates influence only detection probability (and not abundance), they can be incorporated into analyses that use index statistics to draw inferences about abundance (Conroy 1996).

Data resulting from point counts nearly always are treated as indices (Ralph et al. 1995). Standardized methods have been incorporated into large-scale surveys such as the North American Breeding Bird Survey, or BBS (Robbins et al. 1986, Peterjohn et al. 1997). In the BBS, standardization includes such features as duration of count, length of survey route, distance between stops, weather conditions under which surveys are conducted, time of year, etc. Observer identity and experience are recognized as covariates that are likely to be relevant to variation in detection probability (Sauer et al. 1994b, Kendall et al. 1996) and have been incorporated into most serious efforts to draw inferences about abundance from BBS data (Link and Sauer 1997, 1998). Unfortunately, in any count-based survey, many sources of variation in detection probability that are not associated with observable covariates are likely to exist, and these cannot be accommodated in analyses (e.g. Burnham 1981, Johnson 1995).

Here, we make no claim that inferences emerging from historical analyses of data from the BBS or other point-count surveys necessarily are wrong. Instead, we simply express discomfort with the knowledge that such inferences depend on untested assumptions. When the ratio of count statistics is used to estimate the ratio of abundances (e.g. this is termed relative abundance for two locations or population growth rate for the same location at two points in time), it performs best when $p_i = p$ for the i (places or times) involved in the comparison. Such use of the ratio of count statistics can also be viewed as reasonable in the situation where values of p_i are themselves viewed as random variables arising from some distribution that does not change over the times or locations being compared. However, variation in habitat over time and space and temporal changes in climatic variables that affect bird activity and behavior (e.g. Crick et al. 1997) make even this distributional assumption unlikely to be true for many comparisons.

Although use of point-count data as indices may be necessary in some instances, we believe it is sensible to investigate alternative ways to conduct point counts that might permit estimation of detection probabilities associated with the counts. This is the general approach taken in most estimation methods for animal populations, such as capture-recapture sampling (Seber 1982, Lancia et al. 1994). One approach permitting estimation from point-count data is the variable circular plot (Ramsey and Scott 1979, Reynolds et al. 1980) in which distances to detected birds are recorded and resulting data used with distance sampling methods to estimate density. This approach has been used in avian studies (Mountainspring and Scott 1985, Scott et al. 1986, Fancy 1997) but is not widely used by ornithologists. We recommend that variable circular plot methods be given serious consideration for future point-count surveys.

In this paper, we present a double-observer approach that permits estimation of detection probability from point count data. The approach uses two observers and is a modification of a method developed by Cook and Jacobson (1979) to estimate abundance from aerial survey data. We first describe the field-sampling situation and the basic estimation approach. We then discuss alternative estimation models and their implementation using program SURVIV (White 1983). We describe 17 experimental point-count surveys conducted in spring and early summer 1998 to test this double-observer approach, and we present the results of our modeling and estimation efforts with these data. Finally, we discuss the potential utility of this approach for point-count sur-

veys of birds and make recommendations regarding implementation of the method.

METHODS

Field methods.—We assume a sampling situation where multiple locations are selected for point counts within some general area of interest. In the BBS, for example, each route contains 50 stops at which 3-min point counts are conducted. In other studies, we might select, for example, a sample of 10 to 40 points within an area of interest or in patches of similar habitat within a larger area of interest. The approach is most appropriately used when the points are placed in areas of similar habitat, and stratification is recommended when a set of point counts is obtained from discrete habitats between which differences in detection probability are suspected.

Two observers are present during all point counts. At each count (a visit to a single point), one observer is designated as "primary" and the other as "secondary." The primary observer identifies all birds seen and heard and communicates (via speech and gesture) to the secondary observer the species detected and the direction and general distance of the detection. The secondary observer records the species detected by the primary observer but also surveys the area. Birds detected by the secondary observer but not by the primary observer also are recorded by the secondary observer. At the end of each point count, the data are the number of birds of each species (1) detected by the primary observer and (2) missed by the primary observer but detected by the secondary observer.

A key element of the design is that each observer serves both primary and secondary roles on any group of counts. We recommend that observers alternate roles on consecutive counts, with one observer serving as primary at the first point count, secondary at the second count, primary at the third count, and so on. Under this design, each observer will serve as primary observer for half of the point counts. Although reasons exist for preferring the design with alternating primary observers, it is necessary only for each observer to serve as a primary observer on at least one count. This general design leads to stop-level data that are then aggregated over the counts in the group (e.g. all stops on a BBS route, all counts conducted in a particular habitat type on one day) to yield the basic count statistics needed for estimation of abundance for each species detected.

Estimators of Cook and Jacobson (1979).—Although the sampling situation differs from that studied by Cook and Jacobson (1979), for convenience we follow their general notation. Define x_{ij} as the number of individuals counted by observer i ($i = 1, 2$) on stops when observer j ($j = 1, 2$) was the primary observer. As noted above, the counts for the primary observer

include all birds detected, whereas the counts for the secondary observer include only birds detected by this observer that were missed by the primary observer. Define p_i as the detection probability for observer i, which is assumed to be the same whether observer i is serving as the primary or the secondary observer. Further, let N_i denote the true number of birds exposed to sampling efforts (for fixed-radius point counts, we can specify the area covered, whereas for unlimited-radius counts, we cannot) in the point-count samples for which observer 1 served as primary observer. We can view x_{11} as a binomial random variable with parameters N_1 and p_1, denoted as having distribution $B(N_1, p_1)$. For a given x_{11}, we similarly can view x_{21} as a binomial random variable $B(N_1 - x_{11}, p_2)$. The joint distribution of (x_{11}, x_{21}) can thus be written as the product $B(N_1, p_1) B(N_1 - x_{11}, p_2)$. Similarly, the distribution of (x_{22}, x_{12}) can be written as $B(N_2, p_2) B(N_2 - x_{22}, p_1)$. Finally, assuming that the pairs (x_{11}, x_{21}) and (x_{22}, x_{12}) are independent, the joint distribution for all four random variables is $B(N_1, p_1) B(N_1 - x_{11}, p_2) B(N_2, p_2) B(N_2 - x_{22}, p_1)$.

Because values of N_i are unknown, it would be difficult to use the above distribution directly for estimation. Following the recommendation of Cook and Jacobson (1979), we thus condition on the total birds detected in the samples of point counts for which each observer served as primary observer. The probability that a bird in a sampled area is detected at a point count by at least one observer is $p = 1 - (1 - p_1)(1 - p_2)$. This detection probability applies to each of the point counts (or stops) on the route for which it is estimated, and thus to each area ($i = 1, 2$) and the entire area sampled by the counts. Thus, the distribution of $(x_{11} + x_{21})$ is $B(N_1, p)$, and that of $(x_{22} + x_{12})$ is $B(N_2, p)$. Further, the probability of a bird having been detected by observer 1 in area 1, given that it was detected in area 1 (i.e. the probability that a bird was a member of x_{11}, given that it was a member of $x_{11} + x_{21}$) is p_1/p. The complement of this probability, the probability that a bird in area 1 was missed by observer 1 and detected only by observer 2, given that it was detected in area 1, is $(1 - p_1) p_2/p$. For estimation purposes, we thus rewrite the joint distribution of the four random variables as: $B(N_1, p) B(x_{11} + x_{21}, p_1/p) B(N_2, p) B(x_{22} + x_{12}, p_2/p)$.

The approach to estimation begins by using the two conditional (on detections) distributions, $B(x_{11} + x_{21}, p_1/p)$ and $B(x_{22} + x_{12}, p_2/p)$, to estimate detection probabilities. Cook and Jacobson (1979) present the following maximum-likelihood estimators for the general model in which detection probability differs for the two observers:

$$\hat{p}_1 = \frac{x_{11}x_{22} - x_{12}x_{21}}{x_{11}x_{22} + x_{22}x_{21}}, \qquad \hat{p}_2 = \frac{x_{11}x_{22} - x_{12}x_{21}}{x_{11}x_{22} + x_{11}x_{12}}, \quad \text{and}$$

$$\hat{p} = 1 - \frac{x_{12}x_{21}}{x_{22}x_{11}}. \tag{3}$$

Large-sample variance estimators for the detection probability estimates were also provided by Cook and Jacobson (1979) and are presented in Appendix 1.

Note that the estimators in equation 3 can also be obtained simply by equating the four sufficient statistics with their expectations:

$$E(x_{11}) = N_1 p_1, \qquad E(x_{21}) = N_1(1 - p_1)p_2,$$

$$E(x_{22}) = N_2 p_2, \quad \text{and} \quad E(x_{12}) = N_2(1 - p_2)p_1.$$

These equations then can be solved to yield the estimators in equation 3. Examination of these expectations provides a good basis for the intuition underlying the double-observer approach. For example, the expected number of birds detected by observer 1 on the stops at which this observer is primary is given simply as the product of bird abundance at these stops and the detection probability for that observer. The number of additional birds detected by observer 2 on the stops at which observer 1 is primary is given as the product of bird abundance, the probability that a bird is missed by observer 1, and the probability that a bird is detected by observer 2.

Once estimates of detection probability are obtained, the natural estimator (see equation 2) for population size on the sampled area is:

$$\hat{N} = \frac{x_{..}}{\hat{p}}, \tag{4}$$

where $x_{..} = x_{11} + x_{21} + x_{22} + x_{12}$. An associated variance estimator is:

$$\widehat{var}(\hat{N}) = \frac{(x_{..})^2 \widehat{var}(\hat{p})}{\hat{p}^4} + \frac{(x_{..})(1 - \hat{p})}{\hat{p}^2}. \tag{5}$$

The above estimators for abundance (equation 4) and its associated variance (equation 5) are used in all of our work on estimation under the double-observer approach, regardless of the exact model selected for estimation of detection probability.

Confidence intervals for $\hat{N}$ were approximated using the approach of Chao (1989; also used and recommended by Rexstad and Burnham 1991). The estimation is based on the estimated number of birds not detected, $\hat{f}_0 = N - x_{..}$. The $\ln(\hat{f}_0)$ is treated as an approximately normal random variable, yielding the following 95% confidence interval, $(x_{..} + \hat{f}_0/C, x_{..} + \hat{f}_0 C)$, where

$$C = \exp\left(1.96\left[\ln\left(1 + \frac{\widehat{var}(\hat{N})}{\hat{f}_0^2}\right)\right]^{1/2}\right).$$

Additional models and estimators.—For each group of point counts, we consider the modeling of two possible sources of variation in detection probability, observers and bird species. Following Cook and Jacobson (1979), we assume differences in detection probabilities for the two observers. If we also assume dif-

ferent detection probabilities for each bird species, then we have a very general model and must estimate two parameters (a detection probability for each observer) for each species observed. However, large numbers of parameters lead to large sampling variances, so we would like to reduce the number of parameters and model the data parsimoniously (Burnham and Anderson 1992, 1998). Consequently, analyses of double-observer point-count data should include consideration of models in which detection probabilities are similar for the two observers and for different bird species. Most North American point counts contain many species for which only small numbers of individuals are detected, making estimation of species-specific detection probability problematic or impossible. Thus, we would like to consider grouping species for which small samples are obtained. Detection probabilities can then be estimated for these multispecies groups.

Consequently, for reasons of parsimony and small sample sizes for some species, we recommend consideration of grouping of species for modeling and estimation purposes. Because of the binomial nature of detection-probability modeling, such grouping should be done only when detection probabilities of the grouped species are similar. We thus recommend a *priori* grouping of species into general categories associated with predicted variation in detection probabilities (e.g. easy to detect, difficult to detect). Although universal agreement on any such a *priori* grouping is virtually impossible (e.g. Sauer et al. 1996), this approach is subject to a *posteriori* testing. For example, group-specific detection probabilities can be compared and the results used to guide the modeling of detection probabilities in the current analysis (e.g. if no difference between detection probabilities of two groups is evident, then these groups could be modeled with a common detection probability) and in future analyses.

To fit and obtain estimates under different models, to test between models, and to apply model-selection criteria to choose among them, we implemented a series of product-binomial models using program SURVIV (White 1983). Denote a particular species, s, by the use of a superscript. The most general model is based on the following product binomial for each species $B(x_{11}{}^s + x_{21}{}^s, p_1{}^s/p^s) B(x_{22}{}^s + x_{12}{}^s, p_2{}^s/p^s)$. These conditional binomials are multiplied together over all species to obtain the general model, which we denote as (p_i^s) to indicate the dependence of detection probability on observer identity (i) and bird species (s). This very general model permits an "interaction" between observer and species effects on detection probability such that an observer with a relatively high probability of detecting birds of one species can have a relatively low probability of detecting individuals of another species.

We also considered models with a variety of parameter constraints. For example, model (p^s) has the

constraint that detection probability differs by species but within species is the same for each observer $(p_1{}^s = p_2{}^s)$. Because many species are detected a small number of times on a route, models with species-specific detection probabilities will be too general for reasonable estimation and use. Thus, we identified broad categories of species based on expected detectability. Model $(p_i{}^g)$ retains different detection probabilities for the two observers but imposes a constraint on detection probabilities of the different species. The g superscript indicates that species within an *a priori* defined group (e.g. easily detected vs. difficult to detect) exhibit the same detection probability but that this probability differs between groups. Model (p_i) retains different detection probabilities for the two observers but constrains detection probability for all species to be equal.

For a given data set involving species-specific data for all species encountered on point counts, we fit several models and then used Akaike's Information Criterion (AIC) to make decisions about the most appropriate model(s) for use in estimation. AIC is an information-theoretic measure used to select a parsimonious model that adequately explains the variation in the data using as few parameters as necessary (Burnham and Anderson 1992, 1998). Because our sample sizes were not large relative to the number of parameters in our general model, we used AIC_c, a second-order AIC with small-sample bias adjustment.

We then used the resulting estimates, $\hat{p}_i{}^s$, in conjunction with species-specific data (e.g. $x_{..}{}^s$) to estimate abundance for species s using equation 4. Note that even when we selected a model that did not retain species-specific detection probabilities, we still applied the detection probability estimate (e.g. for a group of species or for all species) to the number of individuals observed in the species of interest to estimate abundance for that species. Thus, our approach yielded an estimate of abundance, $\hat{N}^s$, for each species observed in the set of counts.

Regardless of whether a model with detection probability subscripted by i (observer) is selected, the detection probabilities on which the modeling is based correspond to the probability that an individual observer detects a bird that is present in the surveyed area. However, to estimate abundance, we must then translate the estimates for observers 1 and 2 $(\hat{p}_1{}^s, \hat{p}_2{}^s)$ into an estimate of the probability that a bird of species s is detected by at least one of the two observers. For the general Cook-Jacobson model $(p_i{}^s)$, the closed-form estimator, $\hat{p}^s$, is given in equation 3. However, we also need to compute this estimate for the other reduced-parameter models. This is accomplished using the equality:

$$\hat{p}^s = 1 - (1 - \hat{p}_1{}^s)(1 - \hat{p}_2{}^s) \qquad (6)$$

that is, in order to go undetected in the survey $(1 - p^s)$, a bird must be missed by both observers. Follow-

TABLE 1. Descriptive information on the point count surveys conducted using the double-observer approach.

Sur-vey	Observer A	Observer B	Route[a]	No. of stops	Date
1	1	2	PWRC-W1	20	6-14-98
2	1	2	PWRC-F1	10	6-14-98
3	1	2	BBS-A	50	6-20-98
4	1	2	PWRC-W2	20	6-22-98
5	1	2	PWRC-F2	20	6-24-98
6	3	2	PWRC-W1	20	6-25-98
7	3	1	PWRC-W2	20	6-26-98
8	4	1	BBS-B	50	6-28-98
9	5	2	PWRC-W1	20	6-28-98
10	6	1	BBS-C	50	6-30-98
11	6	2	BBS-D	50	7-07-98
12	7	3	PWRC-W1	20	7-07-98
13	7	2	PWRC-F2	20	7-09-98
14	6	3	PWRC-W2	20	7-09-98
15	3	2	PWRC-F2	20	7-14-98
16	8	3	PWRC-F2	20	7-15-98
17	8	3	PWRC-F2	20	7-16-98

[a] PWRC-W1 and -W2 are routes conducted in the woods at Patuxent Wildlife Research Center. PWRC-F1 and -F2 are routes conducted in fields at Patuxent Wildlife Research Center. The BBS routes are actual Maryland BBS routes.

ing model selection using SURVIV, we reparameterize the model using the identity:

$$p_1{}^s = \frac{p_2{}^s - p^s}{1 - p_2{}^s}. \qquad (7)$$

Expression 7 is then substituted for $p_1{}^s$ in the SURVIV code to obtain direct estimates of p^s and associated sampling variances and covariances.

FIELD TRIALS

We carried out the double-observer approach on 17 different sets of point counts (Table 1). Each set consisted of a route of 10 to 50 points. At each point, 3-min point counts were conducted, and all birds seen and heard (unlimited-radius counts) were recorded. Observers then drove to the next site. Most of the routes contained 20 stops and were located at the Patuxent Wildlife Research Center in either field/scrub habitat or woods. In addition, four Maryland BBS routes containing 50 stops were run using the double-observer approach. Stops were located at 0.5-mile intervals. With the exception of the double-observer sampling, point counts were conducted using BBS protocol. Counts occurred in the morning hours and were conducted under reasonable weather conditions. An abbreviated protocol was prepared

TABLE 2. ΔAIC_c values for the six models of detection probability fit to each data set. $\Delta AIC_c = 0.00$ for the model judged to be most appropriate for each data set. Smaller values of ΔAIC_c indicate models that describe the variation in the data more parsimoniously.

Data set	Total birds	Models					
		p_i^s	p^s	p_i^g	p^g	p_i	p
1	231	9.65	0.00	10.47	6.42	7.53	5.58
2	83	7.08	0.42	4.23	0.00	3.17	1.32
3	619	3.40	12.61	—[a]	—	0.14	0.00
4	219	12.78	8.93	3.59	4.92	0.00	2.89
5	321	26.25	16.14	4.05	0.00	5.41	3.41
6	300	10.13	22.32	—	—	0.00	24.08
7	232	6.50	1.91	—	—	4.15	0.00
8	675	24.36	6.17	—	—	2.00	0.00
9	176	6.04	0.00	—	—	1.35	1.97
10	970	0.00	20.50	—	—	10.30	8.51
11	773	0.00	11.29	—	—	12.30	19.74
12	408	29.35	22.94	2.32	11.84	0.00	10.10
13	492	37.77	89.63	0.59	77.59	0.00	77.27
14	228	0.00	4.61	7.30	14.35	4.21	12.54
15	484	9.25	43.41	—	—	0.00	76.54
16	474	39.94	20.92	0.00	9.61	0.07	11.24
17	535	12.11	40.19	—	—	0.00	20.59

[a] Too few individuals in the "difficult detection" group to merit analysis, so only "easy detection" birds were used. In this case, models with a "g" superscript were not relevant.

by observers 1 and 2 following the first few routes and distributed to the other observers prior to their participation in the surveys. The protocol was slightly different for the very last survey (data set 17), because a third person accompanied the two observers to serve as recorder for the primary observer.

The data obtained from these trial routes were analyzed using the SURVIV (White 1983) code developed for this purpose. We used the approach described above with observer, bird species, and species group as potential sources of variation. Under the more general models, we estimated separate parameters for each species for which at least 10 individuals were detected. The remaining species were pooled into one of two groups, "difficult" or "easy," for estimation of a group-level detection probability. We were conservative in our species grouping because we placed only the following species with high-frequency calls in the "difficult detection" group: Brown Creeper (*Certhia americana*), Blue-gray Gnatcatcher (*Polioptila caerulea*), Cedar Waxwing (*Bombycilla cedrorum*), Black-and-white Warbler (*Mniotilta varia*), Prairie Warbler (*Dendroica discolor*), and Grasshopper Sparrow (*Ammodramus savannarum*). For a small number of species, the numbers of individuals detected by the different observers assumed values that led to problems with parameter identifiability (see below). In such cases, the data were pooled with data from the appropriate species group ("difficult" or "easy").

ΔAIC_c values were computed for all 6 models for each of the 17 data sets. These values reflect the difference between the AIC_c value of the model in question and the model with the lowest AIC_c (the model considered the most appropriate for the data set; Burnham and Anderson 1998). Small differences (e.g. $\Delta AIC_c < 2$) indicate models that are very similar in their abilities to explain the data in a parsimonious manner (Burnham and Anderson 1998). The number of detections of birds in the "difficult" category was too small for analysis in nine data sets, so the two models using these species groups (p^g, p_i^g) were not used with these data.

Model p_i showed the lowest AIC_c for the largest number (6) of data sets (Table 2). Models p_i^s and p each showed the lowest AIC_c value for three data sets (Table 2). Models p^g and p^s each were judged most appropriate for two data sets, and model p_i^g showed the lowest AIC_c for a single data set (Table 2). Based on these results, all of the factors hypothesized a priori to be potential sources of variation in detection probabilities indeed were important on at least some routes. Variation between the two observers on each route was an important model factor in 10 of the 17 data sets (models p_i, p_i^g and

TABLE 3. Mean detection probabilities (based on model p_i) for the different observers.

Observer (i)	Number of counts	$\hat{p}_i$	$\widehat{SE}$ ($\hat{p}_i$)[a]
1	7	0.88	0.013
2	10	0.81	0.025
3	7	0.85	0.042
4	1	0.89	0.018
5	1	0.82	0.042
6	3	0.84	0.045
7	2	0.93	0.010
8	2	0.85	0.045

[a] Estimated standard errors are based on replication except for observers 4 and 5, who ran only a single set of counts. Model-based standard error estimates are presented for these observers.

p_i^s) . Point estimates of detection probability for individual observers showed substantial variation, with averages on specific routes ranging from 0.65 to 0.97 (Appendix 2). The average estimated detection probabilities for individual observers over all data sets ranged from 0.81 to 0.93 (Table 3).

Our ability to draw inferences about the difference in detection probabilities of "difficult" and "easy" species was greatly limited by the small number of individuals in the "difficult" category. Nevertheless, model selection results indicated that this distinction was important in three of the six data sets that contained both difficult and easy species and that did not require species-specific detection probabilities. Species group or identity was included in the selected models for 8 of the 17 data sets (Table 2). We used point estimates of detection probability under model p^s to reflect average detection probability for species in the two detection categories (Table 4). The average detection

probabilities over all eight routes for which such estimates could be obtained were 0.67 for difficult species and 0.86 for easy species. A one-tailed paired t-test yielded a test statistic with probability $P = 0.01$ under the null hypothesis of no difference. Thus, despite the poor precision of estimates for the difficult species, our results provided evidence of a true difference in the detection probabilities for these two groups.

To illustrate the actual estimation approach, we computed estimates of abundance for all bird species encountered on one of the sample routes, BBS-C (data set 10). On this route, the general Cook-Jacobson model (p_i^s) was selected as most appropriate for the data set (Table 2). Under this model, separate detection probabilities were estimated for species for which at least 10 individuals were detected (and for which the sufficient statistics did not yield identifiability problems; such problems occurred in two species). Species not meeting the criteria for separate estimation of detection probabilities were categorized as belonging to the "difficult" or "easy" detection groups to estimate group-level detection probabilities. On this particular route, no "difficult" species were detected. We note that model (p_i^s) was a fairly clear choice for data set 10, based on the magnitudes of the ΔAIC_c values for the other models. For data sets where model selection is not so clear, model-averaged estimates of detection probabilities (based on estimates from different models weighted using the ΔAIC_c values; Buckland et al. 1997, Burnham and Anderson 1998) may be a more reasonable approach to estimation of detection probability

TABLE 4. Number of birds observed (n) and estimated detection probability (standard error) for birds in the "difficult detection" and "easy detection" groups based on model p^s.

Data set	Difficult		Easy	
	n	$\bar{p}$ ($\widehat{SE}$ [$\bar{p}$])	n	$\bar{p}$ ($\widehat{SE}$ [$\bar{p}$])
1	6	0.50 (0.433)	225	0.82 (0.033)
2	11	0.63 (0.254)	72	0.93 (0.035)
4	12	0.91 (0.095)	207	0.90 (0.024)
5	12	1.00 (0.213)	309	0.86 (0.024)
12	5	0.75 (0.280)	403	0.87 (0.020)
13	9	0.50 (0.354)	483	0.82 (0.023)
14	4	0.67 (0.385)	224	0.81 (0.034)
16	11	0.43 (0.358)	463	0.85 (0.021)
$\bar{x}$	9	0.67 (0.072)[a]	298	0.86 (0.015)[a]

[a] Standard errors of the mean detection probability estimates were obtained using the data sets as replicates.

and bird abundance. This approach basically involves computing a weighted estimate (e.g. of detection probability) using the estimates from different models weighted by their respective ΔAIC_c values, such that the estimates from models with smaller ΔAIC_c values have larger weights (Burnham and Anderson 1998). Consequently, the parameter estimate is not based solely on the low-AIC_c model, but is most strongly influenced by the models that are judged to be the most appropriate for the data set.

The detection probabilities used to estimate abundance (Table 5) were those corresponding to the probability of a bird being detected by at least one observer (equation 6), as estimated using the substitution of equation 7. It is important to recall that these are not equivalent to the observer-specific detection probabilities that were presented in previous tables and on which modeling was based. For many species, the estimated detection probability was 1 (Table 5). This occurred, for example, when at least one observer detected all of the individuals of a given species that were detected while that person served as primary observer (i.e. the secondary observer detected no additional birds of that species). In such cases, the best estimate of abundance is the number of birds detected, and the variance of $\hat{p}$ (see Appendix 1), and hence of $\hat{N}$, are undefined.

The high detection probabilities produced abundance estimates that are very precise and that are only slightly higher than the actual counts (Table 5). This should not be taken as evidence that standard point counts perform reasonably well in the absence of estimation efforts, because the detection probability estimates for individual observers are substantially lower (Tables 3 and 4, Appendix 2). To obtain abundance estimates that correspond to standard point counts with single observers, we focus on the half of the point counts for which one specific observer served the primary role. We estimate abundance for the survey stops at which primary observer i serves as primary observer by dividing the number of birds detected on these stops by both observers by the estimated detection probability for both observers for the species in question (e.g. $\hat{N}_1{}^s = x_1{}^s/\hat{p}^s$). Such abundance estimates corresponding to half of the survey route, $\hat{N}^s$, can differ substantially from the number counted by the primary observer on these stops, $x_{11}{}^s$ (Table 6), clearly demonstrating the bias associated with use of a count from a standard point-count survey route as an estimate of actual population size.

Discussion

Problems in Applying the Double-Observer Approach

Results from our field trials indicate that the double-observer approach to estimation of detection probabilities can be applied usefully to point counts. The field methods and the subsequent modeling and estimation appear to be reasonable and to yield reasonable results. As in any field implementation of an estimation procedure, our attempts to use this approach were not without problems. Here, we discuss the main problems and difficulties that we encountered.

Field application.—This approach requires that detection of a bird by the primary observer be independent of detection by the secondary observer. If the primary observer notices the secondary observer focusing attention in a particular direction, then the primary observer may focus attention similarly. The act of the secondary observer writing down an observation when the primary observer has not indicated a detection can serve as a cue to the primary observer. To minimize the provision of cues by the secondary observer, we recommend that the secondary observer attempt to remain directly behind the primary observer and out of his/her field of vision. Clearly, this is easier said than done, because the primary observer will be constantly turning his/her head to detect birds, so the recommendation is simply that the secondary observer stay behind the primary observer to the extent possible.

If it appears that recording observations by the secondary observer is serving as a cue to the primary observer (this will likely be a problem only when few birds are present), then the secondary observer should probably go through the motions of recording (even to the point of scribbling on the data sheet) at times when no birds are detected. Similarly, the secondary observer must sometimes focus binoculars on a specific position to identify a detected bird. Again, we recommend that the secondary observer attempt to disguise the location of the observed bird to the degree possible by

scanning areas and focusing on locations without, as well as with, detected birds. In many (perhaps most) point counts, most birds are detected by hearing, and such detections are least likely to provide cues to the other observer.

We have not formally investigated the consequences of dependent detection probabilities, but we believe that they will yield estimates of detection probability that are biased high (and abundance estimates that are biased low). Although every effort should be made to reduce dependence among detection probabilities, even with such dependence, the double-observer approach is preferable to counts in which detection probabilities are assumed to be 1. That is, the positive bias in detection probability estimates will never be larger for the double-observer approach than for standard point counts, and it will nearly always be smaller.

Another potential problem involves the assumption that an observer's detection probability is the same regardless of whether the person is serving a primary or secondary role. At points with small to moderate numbers of birds, this assumption was not perceived to be a problem. In areas with many birds, however, secondary observers sometimes believed that their detection probabilities were reduced because of their recording duties. If this is believed to be a substantial problem, then it may be necessary to use a third person who would serve as recorder for the primary observer. As noted, we followed this approach on the last survey (data set 17), and it appeared to work reasonably well. Another possible solution is to have both the primary and secondary observers record the data from the primary observer. This redundancy would serve no purpose with respect to the actual data collection but would serve to make detection probabilities as similar as possible for a person in the two different observation roles.

The problem that we view as potentially the most serious involves differences in distances at which different observers detect birds. The double-observer approach deals well with simple differences in detection probabilities (one observer is more likely to detect a bird of a particular species than is the other observer), and our results provided strong evidence of variation among observers in detection probabilities. However, the above models were developed assuming that the same group of birds

was potentially detectable by both observers, whereas in reality it may be that one observer detects birds from a much larger distance than the other observer. In this situation, a group of birds may be undetectable by one observer and detectable by the other. This situation can lead to the detection probabilities for a particular observer appearing to change according to the identity of the observer with whom he/she is paired. Of course, this problem is not unique to the double-observer approach.

A reasonable approach to dealing with this problem is to use fixed-radius point counts rather than unlimited-radius counts. The fixed radius would be set to a value for which the possibility that birds are undetectable approaches zero (i.e. the radius would be sufficiently short that all observers would be able to detect birds at that distance). The argument against fixed-radius counts is that it is difficult to judge distances accurately, and that such inaccuracies will translate into ambiguity and variation among observers in actual distances over which birds are detected. Certainly, this is true to some extent, and no two observers will be recording birds from the same exact distances. Nevertheless, we suspect that variation among observers in distances at which birds are detected will be much smaller for fixed-radius counts than for unlimited-radius counts. Training can be used to increase an observer's ability to distinguish distance to a fixed counting radius. An alternative approach for dealing with differences among observers in detection radii involves development of models that specifically incorporate parameters associated with these differences (see below).

Other minor problems exist in application of the double-observer approach. In some cases, the secondary observer will disagree with the identity of a species determined by the primary observer. In cases of a passing flock or group of birds, the counts of the primary and secondary observers may differ. In the absence of any information indicating greater faith in one observer over the other, we have assumed that the primary observer has correctly identified and enumerated detected birds. Such disagreements did not occur frequently, and arbitrary resolution (primary observer is always right) seems as reasonable as any approach. Obviously, this sort of problem is not unique to the double-observer approach. Errors made by a single

TABLE 5. Number of birds counted, and estimated detection probability and abundance, for species detected on BBS-C (data set 10).

Species	$x..$	Detection probability		Abundance		
		$\hat{p}$	$\widehat{SE}(\hat{p})$	$\hat{N}$	$\widehat{SE}(\hat{N})$	95% CI
Great Blue Heron (*Ardea herodias*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Cattle Egret (*Bubulcus ibis*)	2	0.9625	0.0159	2.08	0.29	2.00 to 3.92
Turkey Vulture (*Cathartes aura*)	47	0.9865	0.0159	47.64	1.11	47.06 to 53.46
Canada Goose (*Branta canadensis*)	21	0.9625	0.0159	21.82	0.99	21.13 to 26.26
Mallard (*Anas platyrhynchos*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
American Kestrel (*Falco sparverius*)	4	0.9625	0.0159	4.16	0.41	4.01 to 6.60
Ring-necked Pheasant (*Phasianus colchicus*)	2	0.9625	0.0159	2.08	0.29	2.00 to 3.92
Northern Bobwhite (*Colinus virginianus*)	44	0.9808	0.0218	44.86	1.37	44.10 to 51.77
Killdeer (*Charadrius vociferus*)	6	0.9625	0.0159	6.23	0.50	6.02 to 9.08
Rock Dove (*Columba livia*)	38	1.0000	—	38.00	—	
Mourning Dove (*Zenaida macroura*)	29	1.0000	—	29.00	—	
Yellow-billed Cuckoo (*Coccyzus americanus*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Chimney Swift (*Chaetura pelagica*)	5	0.9625	0.0159	5.19	0.46	5.01 to 7.85
Ruby-throated Hummingbird (*Archilochus colubris*)	3	0.9625	0.0159	3.12	0.35	3.01 to 5.30
Red-bellied Woodpecker (*Melanerpes carolinus*)	6	0.9625	0.0159	6.23	0.50	6.02 to 9.08
Downy or Hairy woodpecker (*Picoides pubescens, P. villosus*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Northern Flicker (*Colaptes auratus*)	7	0.9625	0.0159	7.27	0.55	7.02 to 10.28
Pileated Woodpecker (*Dryocopus pileatus*)	2	0.9625	0.0159	2.08	0.29	2.00 to 3.92
Eastern Wood-Pewee (*Contopus virens*)	7	0.9625	0.0159	7.27	0.55	7.02 to 10.28
Acadian Flycatcher (*Empidonax virescens*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Eastern Phoebe (*Sayornis phoebe*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Great Crested Flycatcher (*Myiarchus crinitus*)	5	0.9625	0.0159	5.19	0.46	5.01 to 7.85
Eastern Kingbird (*Tyrannus tyrannus*)	2	0.9625	0.0159	2.08	0.29	2.00 to 3.92
Red-eyed Vireo (*Vireo olivaceus*)	28	1.0000	—	28.00	—	
Blue Jay (*Cyanocitta cristata*)	22	0.9899	0.0150	22.22	0.58	22.01 to 25.71
American Crow (*Corvus brachyrhynchos*)	16	1.0000	—	16.00	—	
Fish Crow (*Corvus ossifragus*)	8	0.9625	0.0159	8.31	0.59	8.03 to 11.46
Horned Lark (*Eremophila alpestris*)	2	0.9625	0.0159	2.08	0.29	2.00 to 3.92
Purple Martin (*Progne subis*)	15	0.9625	0.0159	15.58	0.82	15.08 to 19.52
Tree Swallow (*Tachycineta bicolor*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Barn Swallow (*Hirundo rustica*)	12	1.0000	—	12.00	—	
Carolina Chickadee (*Poecile carolinensis*)	2	0.9625	0.0159	2.08	0.29	2.00 to 3.92
Tufted Titmouse (*Baeolophus bicolor*)	9	0.9625	0.0159	9.35	0.62	9.03 to 12.64
White-breasted Nuthatch (*Sitta carolinensis*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Carolina Wren (*Thryothorus ludovicianus*)	11	1.0000	—	11.00	—	
Eastern Bluebird (*Sialia sialis*)	5	0.9625	0.0159	5.19	0.46	5.01 to 7.85
Wood Thrush (*Hylocichla mustelina*)	16	1.0000	—	16.00	—	
American Robin (*Turdus migratorius*)	72	0.9924	0.0083	72.55	0.96	72.05 to 77.60
Gray Catbird (*Dumetella carolinensis*)	5	0.9625	0.0159	5.19	0.46	5.01 to 7.85
Northern Mockingbird (*Mimus polyglottos*)	34	1.0000	—	34.00	—	
Brown Thrasher (*Toxostoma rufum*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
European Starling (*Sturnus vulgaris*)	55	0.9778	0.0193	56.25	1.58	55.18 to 63.51
Northern Parula (*Parula americana*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Kentucky Warbler (*Oporornis formosus*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Common Yellowthroat (*Geothlypis trichas*)	13	1.0000	—	13.00	—	
Summer Tanager (*Piranga rubra*)	1	0.9625	0.0159	1.04	0.20	1.00 to 2.39
Scarlet Tanager (*Piranga olivacea*)	4	0.9625	0.0159	4.16	0.41	4.01 to 6.60
Eastern Towhee (*Pipilo erythrophthalmus*)	3	0.9625	0.0159	3.12	0.35	3.01 to 5.30
Chipping Sparrow (*Spizella passerina*)	15	1.0000	—	15.00	—	
Field Sparrow (*Spizella pusilla*)	6	0.9625	0.0159	6.23	0.50	6.02 to 9.08
Song Sparrow (*Melospiza melodia*)	8	0.9625	0.0159	8.31	0.59	8.03 to 11.46
Northern Cardinal (*Cardinalis cardinalis*)	21	1.0000	—	21.00	—	
Blue Grosbeak (*Guiraca caerulea*)	17	0.9815	0.0279	17.32	0.75	17.02 to 21.71
Indigo Bunting (*Passerina cyanea*)	24	0.9545	0.0550	25.14	1.82	24.13 to 34.31
Red-winged Blackbird (*Agelaius phoeniceus*)	114	0.9973	0.0024	114.31	0.63	114.03 to 117.76

TABLE 5. Continued.

Species	$x_{..}$	Detection probability $\hat{p}$	$\widehat{SE}(\hat{p})$	Abundance $\hat{N}$	$\widehat{SE}(\hat{N})$	95% CI
Eastern Meadowlark (*Sturnella magna*)	5	0.9625	0.0159	5.19	0.46	5.01 to 7.85
Common Grackle (*Quiscalus quiscula*)	87	0.9661	0.0205	90.06	2.61	87.72 to 100.05
Brown-headed Cowbird (*Molothrus ater*)	11	1.0000	—	11.00	—	
Orchard Oriole (*Icterus spurius*)	6	0.9625	0.0159	6.23	0.50	6.02 to 9.08
Baltimore Oriole (*Icterus galbula*)	4	0.9625	0.0159	4.16	0.41	4.01 to 6.60
House Finch (*Carpodacus mexicanus*)	11	1.0000	—	11.00	—	
American Goldfinch (*Carduelis tristis*)	11	1.0000	—	11.00	—	
House Sparrow (*Passer domesticus*)	56	0.9969	0.0039	56.17	0.47	56.01 to 59.02

observer conducting a point count simply go unchallenged. The best way to circumvent this problem is to try to insure that all observers are experts at bird identification and observation.

Some bird species are virtually undetectable in daytime surveys such as those reported here (e.g. owls and nightjars). Even if an individual of such a species is detected now and then, it will be impossible to estimate associated detection probabilities. Thus, although the double-observer approach holds promise for species with reasonable detection probabilities (e.g. >0.40), the approach will not be useful for species with detection probabilities that approach 0. Similarly, in some situations certain classes of individuals (e.g. females) will have detection probabilities that approach 0, in which case estimates of detection probability and abundance for the species would correspond to the classes of individuals that have non-zero detection probabilities. Clearly, undetectable species and individuals present problems in any type of

survey, and if these species or classes are of primary interest, then an alternative sampling approach should be used (e.g. capture-recapture methods rather than observation-based methods).

Computations.—Under certain combinations of values of the sufficient statistics, the parameters of interest are not identifiable and cannot be well estimated. One such situation is when only one observer detects individuals of a particular species (e.g. $x_{11} > 0$, $x_{12} > 0$, $x_{22} = 0$, $x_{21} = 0$). In this situation, the denominator of the estimator (equation 3) for the observer who detected birds is 0, and the estimator is undefined. If $x_{11} x_{22} - x_{12} x_{21} = 0$, and $x_{ij} > 0$ ($i = 1, 2; j = 1, 2$), then the two detection probabilities are not identifiable. When we encountered such situations for particular species in our analyses, we did not attempt to estimate a species-specific detection probability but pooled the data for the problem species with the other species in the same detection group (i.e. difficult or

TABLE 6. Number of birds counted by observer 1 (x_{11}), estimated abundance[a] ($\hat{N}_1$), and estimated species-specific detection probabilities for stops at which observer 1 was the primary observer for selected bird species[b] detected on BBS-C (data set 10).

Species	x_{11}	Abundance $\hat{N}_1$	$\widehat{SE}(\hat{N}_1)$	95% CI	Detection probability $\hat{p}_1$	$\widehat{SE}(\hat{p}_1)$
Turkey Vulture	33	37.51	0.94	37.05 to 42.52	0.8799	0.0581
Northern Bobwhite	13	19.37	0.75	19.03 to 23.53	0.6711	0.1119
Blue Jay	11	12.12	0.40	12.01 to 14.62	0.9074	0.0892
American Robin	22	29.22	0.53	29.01 to 32.33	0.7529	0.0816
European Starling	27	29.66	1.01	29.08 to 34.67	0.9103	0.0619
Blue Grosbeak	6	7.13	0.42	7.01 to 9.76	0.8413	0.1479
Red-winged Blackbird	54	58.16	0.42	58.01 to 60.71	0.9285	0.0346
Common Grackle	39	45.55	1.59	44.29 to 52.19	0.8563	0.0615
House Sparrow	19	20.06	0.26	20.00 to 21.78	0.9471	0.0516

[a] $\hat{N}_1 = x_1 / \hat{p}$.

[b] Selected species were those for which species-specific detection probabilities were estimated and for which $\hat{p} < 1$.

easy) that did not have adequate data for separate estimation. Finally, detection probability estimates of 0 or 1 produce undefined variances (see Appendix 1).

ADDITIONAL MODELING OF DETECTION PROBABILITY

Our intent is to present the basics of the double-observer approach to the conduct of point counts. In the process of examining our data and considering the approach, we identified several other possible extensions to the modeling of detection probabilities. Our results indicate that observer identity and bird species are sources of variation that should be incorporated into virtually all attempts to model detection probability. During our field trials, bird detections were categorized as occurring by visual or by auditory means. Detection probabilities associated with these two modes of detection are likely to be different, and it would be possible to build models that incorporate mode of detection. We suspect that any gains in ability to model detection probabilities would not merit the extra parameters associated with such models, but we do not know this and believe that such modeling should be investigated.

Habitat may be an important source of variation in detection probabilities. It would be possible to classify habitats associated with different point counts according to a simple classification scheme and then incorporate habitat type into models of detection probability.

We found it necessary to group species into broad categories based on ease of detection because small numbers of individuals were detected for many bird species. Certainly, it would be possible to consider different classification schemes and to test their efficacy with data from our field trials or from new efforts. In particular, our "difficult" detection category contained a small number of species, none of which was very abundant in the areas surveyed in our field trials. If the "difficult" category contained more species, then it would be more likely that at least a group-specific detection probability could be estimated. We can also envision species being placed into different detection categories depending on phenology and survey timing, as when males of some species stop singing earlier in the breeding season than do males of other species.

Point counts are used in a variety of types of investigation ranging from broad surveys such as the BBS, to intensive studies of particular sites or locations. Multiple counts by specific observers will permit additional modeling of detection probability that should prove useful in estimating bird abundance. Our field trials perhaps are analogous to intensive research investigations in that some individuals served as observers on many routes and occasions. In such situations, we can create models containing multiple surveys (surveys at different times and places) that share at least some observers. Then, reduced-parameter models can be considered in which species-specific detection probabilities for a particular observer are modeled as constants over time/space or perhaps time/habitat. Even in large-scale surveys in which a pair of observers may conduct only one survey route per year, it may be possible to exploit data from a single observer obtained over multiple years. Such modeling should result in gains in precision.

Multiple routes with specific pairings of investigators also may be an approach to deal with the problem of two observers having different distances from which they can detect birds (different detection radii). Such modeling might require that each individual be paired with every other individual in a small group of investigators. Given data from such multiple routes, parameters reflecting variation in observer detection radius can be incorporated into modeling efforts to standardize detection-probability estimates to correspond to birds that are potentially detectable.

We might categorize the Cook-Jacobson model and our various extensions as "conditional" in that estimation is conducted by first conditioning on the numbers of birds observed, estimating detection probability from such a conditional distribution, and then applying the estimates of detection probability to numbers of birds observed to estimate abundance. In the future, we will consider the possibility of developing unconditional models that incorporate abundance or annual population growth rate directly as model parameters.

RECOMMENDATIONS

We were sufficiently encouraged by the double-observer approach that we believe it should

be strongly considered for use in future point-count studies. In particular, the variation in estimated detection probabilities we document for single-observer counts provides a strong argument against use of these counts when results are to be compared over space or time. Because detection probabilities could vary among the counts being compared (e.g. associated with an experimental treatment), investigators cannot make statements about differences in population sizes based on observed differences in counts. Based on our results, we see little justification for use of standard point counts unaccompanied by some effort to estimate detection probability. The variable circular plot and the double-observer approach described here offer two distinctly different approaches to estimation of detection probability, and hence bird abundance, from point counts. Both require additional effort beyond that required for simple counts, but it is our opinion that most questions that are sufficiently important to merit the effort required to conduct point counts in the first place also are sufficiently important that estimation should be taken seriously.

Computations associated with estimation under the general Cook-Jacobson model are straightforward (e.g. equations 3 and 4) and can be done easily on a hand calculator. The SURVIV models are available at <www.mbr-pwrc.usgs.gov/software/dobserv.html>, as is a more user-friendly Visual Basic program to implement detection probability modeling.

We have pointed out potential problems with our initial efforts to apply the double-observer approach, but most of these problems are even more serious for standard point counts. The situation with point counts that do and do not incorporate attempts to estimate detection probability is analogous to uses of capture-recapture data that do and do not attempt to estimate capture probability. Proponents of the use of raw catch statistics once claimed that they preferred their approach because it was free of the assumptions required by efforts to model and estimate capture probability. This claim was shown to be false, and indeed the "estimators" based on catch statistics were shown to be much more sensitive to assumption violations than were the probabilistic estimators based on modeling capture probability (Jolly and Dickson 1983, Nichols and Pollock 1983, Skalski and

Robson 1992). Although this has not been formally investigated with point counts, we believe that abundance and trend estimates based on the double-observer approach are likely to be much more robust to the various problems discussed above than are estimates based on single-observer counts.

Our primary recommendation regarding implementation of the double-observer approach is the restriction to fixed-radius counts. We believe that two very important advantages are associated with use of a fixed radius. The first advantage has been discussed above and involves an attempt to minimize the probability that a group of birds (e.g. at a particular distance) will be undetectable by one observer, yet detectable by another. The second involves the issue of geographic or spatial sampling. In our treatment above, we followed the traditional treatment of point-count data and omitted discussion of the area sampled and of spatial variation in bird abundance and density. However, spatial variation is easily (and usefully) included in the double-observer approach.

Consider the goal of density or abundance estimation for some large area of interest. One approach to such estimation would be to randomly select locations for the conduct of point counts from all possible locations in the area of interest (stratification could also be used with random selection within strata). The double-observer sampling at the selected points would then cover a known area (equal to $k\pi r^2$, where k denotes the number of point counts conducted and r denotes the fixed radius) and a known fraction of the total area of interest. The abundance estimates from the sampled area can then be used to estimate the total density and abundance on the entire area of interest. The variance of this overall estimate of abundance or density will then depend not only on the precision of the estimate of detection probability, but also on the fraction of the total area on which counts were conducted and on the spatial variation in bird density and abundance (Cook and Jacobson 1979, Lancia et al. 1994). This latter spatial variation results in the need to include in the overall variance estimator a variance component associated with the count-to-count (and place-to-place) variance in number of birds detected. Such estimation of overall abundance or density and its variance is straightforward and is presented in Cook and

Jacobson (1979). Whether the objective of the point-count survey involves monitoring goals or specific study goals, inclusion of spatial variation in bird abundance or density likely will yield stronger and more widely applicable inferences.

A final recommendation is to investigate the potential for use of independent observers to collect point-count data. Two or more observers would detect birds at the same point and the same time, recording the approximate locations and detection times of birds seen and heard on a rough map. After the point count, the different maps would be used to determine which birds were detected by which observer(s). Resulting data would have the form of a capture history, with a vector of 0s and 1s indicating for each bird the observers that did (1) and did not (0) detect it. If detections of the different observers are really independent, then the resulting data can be used with the entire suite of closed-population capture-recapture models (Otis et al. 1978, Rexstad and Burnham 1991). This model set includes models that permit detection probability to be different for each individual bird in the sampled area, and we suspect that such models would prove useful for point-count data. Our primary reason for not exploring this approach was our a priori belief that it would be very difficult in the field to insure independence of observers who were counting birds at the same point. However, Ted Simons (pers. comm.) has experimented with this approach, and his initial results suggest that this sort of sampling is possible.

Note that this final recommendation involves multiple observers sampling at the same point in space and time. This approach is not the same as a single observer surveying the same point(s) on multiple occasions (e.g. days). Although data from this latter approach can be used to estimate species-specific detection probabilities, the estimates are very model dependent and relatively imprecise (Carrol and Lombard 1985, Sauer et al. 1994a). Sampling using variable circular plots and the double-observer approach should be preferable to this latter approach. Multiple surveys by the same pair of observers using the double-observer approach at each survey can be modeled using the approach described here and should produce more precise estimates of detection probability and abundance, as well as inferences about possible changes in abundance over the repeat visits.

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APPENDIX 1. Estimation of variances of detection-probability estimates based on Cook and Jacobson (1979).

Large-sample variances and covariances for individual detection probability estimates are given by Cook and Jacobson (1979) as:

$$\text{var}(\hat{p}_1) = \frac{p_1(1 - p)(1 - \beta_1 p)}{x.. p_2(1 - p_2)\beta_1\beta_2},$$

$$\text{var}(\hat{p}_2) = \frac{p_2(1 - p)(1 - \beta_2 p)}{x.. p_1(1 - p_1)\beta_1\beta_2},$$

$$\text{cov}(\hat{p}_1, \hat{p}_2) = \frac{(1 - p)}{x.. \beta_1\beta_2}, \tag{8}$$

where $\beta_i = x._i/x..$. They also give the following asymptotic variance of the estimated detection probability for both observers, $\hat{p}$:

$$\text{var}(\hat{p} \mid x..) = \frac{(1 - p)^2 p}{x..}\left[\frac{1}{p_1\beta_1} + \frac{1}{p_2\beta_2} + \frac{1}{p_2(1 - p_1)\beta_1} + \frac{1}{p_1(1 - p_2)\beta_2}\right]. \tag{9}$$

These expressions can be used to compute estimates of the variances of detection probability estimates under a general model in which detection probabilities are assumed to be different for the two observers. In practice, we obtain our variance and covariance estimates for $\hat{p}_1$ and $\hat{p}_2$ directly from the appropriate model in program SURVIV. To compute a variance estimate for the overall detection probability, $\hat{p}$, we rewrite p_1 as a function of p (equation 7). This expression (equation 7) is substituted for p_1, and the SURVIV output then contains estimates of p_2, p, and their variances.

APPENDIX 2. Estimated average detection probability (from model p) and detection probabilities for specific observers (from model p_j).

| Data set | Observers | | Detection probability, $\hat{p}_j$ ($\widehat{SE}$ [$\hat{p}_j$]) | | |
	A	B	A	B	Average
1	1	2	0.82 (0.039)	0.81 (0.043)	0.82 (0.033)
2	1	2	0.91 (0.049)	0.88 (0.051)	0.89 (0.040)
3	1	2	0.88 (0.020)	0.84 (0.023)	0.86 (0.017)
4	1	2	0.94 (0.024)	0.86 (0.036)	0.90 (0.024)
5	1	2	0.88 (0.025)	0.87 (0.033)	0.87 (0.022)
7	3	1	0.86 (0.034)	0.87 (0.035)	0.87 (0.027)
6	3	2	0.96 (0.019)	0.77 (0.035)	0.85 (0.026)
15	3	2	0.97 (0.013)	0.70 (0.034)	0.84 (0.021)
8	4	1	0.89 (0.018)	0.89 (0.018)	0.89 (0.014)
9	5	2	0.82 (0.042)	0.90 (0.038)	0.85 (0.034)
10	6	1	0.86 (0.017)	0.85 (0.017)	0.86 (0.014)
11	6	2	0.90 (0.017)	0.83 (0.020)	0.86 (0.015)
14	6	3	0.75 (0.042)	0.90 (0.034)	0.81 (0.034)
13	7	2	0.94 (0.017)	0.66 (0.035)	0.81 (0.023)
12	7	3	0.92 (0.021)	0.81 (0.030)	0.87 (0.020)
16	8	3	0.89 (0.022)	0.78 (0.030)	0.84 (0.021)
17	8	3	0.80 (0.031)	0.65 (0.034)	0.72 (0.029)

Appendix J
Incidental Species List

The following is a list of species which should be entered on the field forms if they are encountered along the specified route.

Temperate breeding shorebirds:

Mountain Plover	MOUP
Willet	WILL
Upland Sandpiper	UPSA
Marbled Godwit	MAGO

Grouse:

Lesser Prairie-Chicken	LPCH
Greater Prairie-Chicken	GPCH
Sharp-tailed Grouse	STGR
Greater Sage-Grouse	GSGR

Raptors:

Short-eared Owl	SEOW
Burrowing Owl	BUOW

Mammalian Predators:

Coyote	CANLA
Red Fox	VULVU
Swift/Kit Fox	VULVE
Gray Fox	UROCI
American Badger	TAXTA
Striped Skunk	MEPME
Raccoon	PROLO